"*I would have everie man write what he knowes and no more.*"—MONTAIGNE

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EDITORIAL

THIS is a notable month for the specialty of Anaesthesia, for during it will be held the first International Congress of Anaesthetists at Scheveningen, Holland. There have, of course, been other International Congresses of Anaesthetists, notably those organized by the International Anaesthetic Research Society, but never before in the organization of which the many Anaesthetic Societies and Associations throughout the world have collaborated. At this Congress will be born a Federation of all these Societies. We are confident that these youngsters coming into the world under such auspices will not suffer from any neonatal disorders, and we wish it not only a happy birthday but also a flourishing and influential future. Such a Federation can do nothing but good. It will enable stronger members to give a helping hand to their younger and more feeble brethren. It will, of course, from time to time organize an international gathering of the sort that is to take place at Scheveningen. Those who are fortunate enough to be present in this delightful Dutch resort during the meeting will welcome the opportunity of partaking of the fascinating and interesting fare which has been prepared for them by the industrious organizing committee. But such an occasion is also an ideal way of meeting colleagues from far and scattered lands. This will be a wonderful opportunity of reunion, where many teachers from Great Britain and United States are likely to meet once again their past pupils, now probably firmly established in their own countries.

We, the *British Journal of Anaesthesia*, wish this Congress the very greatest of success and congratulate the Organization on the programme they have prepared, which promises to provide a fascinating week which will be remembered long in the history of our specialty.

This Journal will be publishing, in its next issue, a report and personal impression of the proceedings at the Congress; when a fuller account of the various papers will be possible.

In the meantime some of us who have practised subcutaneous oxygen therapy will be interested to learn from Dr. Evans of any important developments in this unusual method of giving oxygen.

HUMPHRY DAVY was born December 17, 1778, at Penzance. His early days were spent not so much with his family as with John Tonkin, a surgeon. He was one of those fortunate individuals with a mind capable of taking a keen interest in widely different aspects of life. He had an intense love of scenery and, as closely connected therewith, natural history, geology and fishing. He had a phenomenal memory and Southey appears to have thought highly of him as a poet. He was apprenticed to one Borlase with the idea of becoming a doctor. He made and inhaled vast quantities of nitrous oxide and came near to discovering it as an anaesthetic. How near and just why he didn't is well described in Dr. Cartwright's book *The English Pioneers of Anaesthesia*. His claim to fame, however, rested on his researches in physics and chemistry, his brilliant lectures on these subjects, and his invention of the Davy safety lamp for miners. He was knighted on April 8, 1812, and became President of the Royal Society on November 30, 1820. He died May 28, 1829.

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SOME OBSERVATIONS ON ANAESTHETIC SODA LIME

BY

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A GREAT deal of work has been done on the use of soda lime for carbon dioxide absorption in anaesthesia, much of which has been described by Adriani (1946). In the course of a laboratory study of carbon dioxide absorption, some further information has been obtained, and this is described here.

This paper does not deal expressly with the carbon dioxide absorptive efficiency (which determines the concentration returned to the patient) or the effective life of a charge of soda lime, as these depend to a very large extent on the apparatus in which the soda lime is used. Several of the items discussed in this paper, however, have considerable bearing on these topics, and these influences are described.

SIZE OF GRANULES

It is well known that, in this country, anaesthetic soda lime is invariably a nominal 4–8 mesh or finer. The *British Pharmacopoeia* (1953) stipulates a nominal 3–6 mesh, but this has since been modified to 4–8 mesh (Amendments, September 1954).

In deciding on the most suitable mesh range for anaesthetic soda lime, a number of factors must be considered. Those factors in favour of a coarser mesh are:

(*a*) A coarser mesh has a lower resistance to air-flow.

(*b*) With a very fine mesh, there is some tendency to caking.

On the other hand, there are advantages in using finer mesh material. These are:

(*a*) A finer material presents a larger surface area for the same mass, so that the absorptive efficiency is increased.

(*b*) With a particle of smaller effective radius, the rate of regeneration of the surface is greater, as the carbonate ions formed by the absorption have a shorter distance to diffuse before reaching the interior of the granule.

(*c*) More of a finer soda lime is contained in the canister, particularly with a wider mesh range, giving a greater absorptive capacity.

(*d*) With finer mesh soda lime, effects due to channelling (see below) are decreased, giving a longer fully effective life, particularly on a circle system.

(*e*) With a finer mesh soda lime, particularly with a wider mesh range, the intergranular air space is reduced, so that on a to-and-fro or a Coxeter-Mushin system the dead space of the system is reduced, this benefit being particularly noticeable when the charge is partly exhausted.

Of these factors, unless extreme sizes are used, differences in channelling will have little significance, while caking occurs only with a very fine mesh, more so if the moisture content is high (Adriani, 1941). Hence the benefits which result from the use of a finer and wider mesh range must be weighed against the increased resistance to air flow.

This latter is a function not only of particle size and size range, but also of particle shape and surface condition, and method of packing, and so cannot be connected mathematically with the particle size. However, during examination of a large number of soda lime samples, we have found that excessive resistance (i.e. above 0.5 cm of water at 25 l. per min across an 8×13 cm Waters canister) does not occur until mesh ranges of the order of 6–10 are encountered. In one experiment, some nominally 4–8 mesh soda lime, which had a resistance of 0.24 cm of water at 25 l. per min, was sieved. The same canister filled with the 4–6 mesh fraction (65 per cent of the whole) had a resistance of 0.22 cm of water, and the 6–8 mesh fraction (30 per cent of the whole) gave a resistance of 0.32 cm of water.

The point concerning the reduced dead space with finer material could assume some importance in to-and-fro systems, particularly when the charge is partly exhausted, since the dead space then includes that of the exhausted material, and becomes comparable with the tidal volume.

The fact that a finer mesh soda lime gives longer and more efficient absorption has been demonstrated experimentally. Some 4–8 mesh soda lime was ground and sieved to give an 8–10 mesh sample, which was then shown to absorb much longer and more efficiently than the original material.

We have reached the conclusion that the optimum mesh range for anaesthetic soda lime is 4–8. Other workers (Adriani, 1946; Conroy and Seevers, 1943) stress the importance of obtaining a large surface area, and agree that the best balance between this and increased resistance is obtained with a 4–8 mesh soda lime.

DUST

As is well known, one of the drawbacks of the use of soda lime is the emission of dust from the canister, particularly with poor quality materials. This dust can reach the patient in a Waters system, with its short air path, and could impair valve performance on circle systems.

Some experiments were carried out with various types of filter, in an attempt to trap this dust as or before it left the canister.

One type of filter tried consisted of greased baffles. These were found to be inefficient and easily clogged, and this approach was not pursued.

Another type of filter tried was a water trap. In this, a wide inlet tube reached almost to the surface of water in a 4-oz bottle, and an annular outlet tube around the inlet led away from the top (fig. 1). It was found that a trace of detergent in the water greatly increased the efficiency, and that the optimum distance between the end of the inlet tube and the liquid surface was one inch. Under these conditions, the resistance of the trap at a flow of 25 l. per min was 0.14 cm of water, and over 95 per cent of dust blown into it was

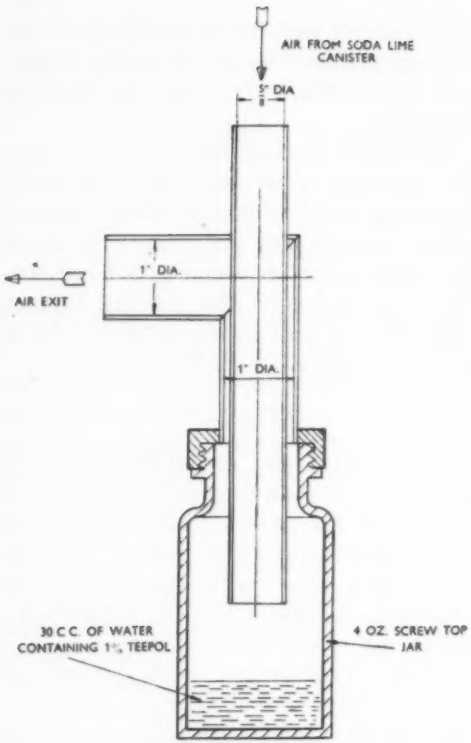

FIG. 1
Water dust trap for use with "circle" arrangement

retained. This trap cannot be used on a Waters canister, but might be useful with a circle absorber, though considerable modification of the present equipment would be needed.

The main method of dust retention studied consisted of the insertion of a layer of filtering material between the soda lime and the canister gauze. A wide range of steel cloths, filter cloths, flannel cloths, mutton cloths, and glass cloths were tried, both alone and moistened with various mixtures of glycerol and detergent. All were found to be either inefficient filters or of too high resistance and readily clogged.

Cotton-wool filter pads were then tried, and found to be very satisfactory, provided they were not too thick. Suitable pads are available commercially ready cut, and are much more satisfactory than pieces cut from a roll. The increase in resistance to an air flow of 25 l. per min in a filled Waters canister varied between 0.16 and 0.3 cm of water. This increase would be imperceptible to the patient. It was shown that dust retention was complete, and that no appreciable increase in resistance due to clogging occurred during the life of the soda lime.

Hence a cotton-wool pad inserted between the soda lime and the canister gauze appears to be a very satisfactory way of preventing dust emission. It can be used in either a Waters canister or a circle absorber, and can be replaced at the same time as the soda lime.

CHANNELLING

The nature of the air flow within the canister is of importance in estimating the efficiency of carbon dioxide absorption. It has been shown (Adriani, 1941, 1946) that the gases tend to pass preferentially along the sides of the canister, and it was decided to repeat this experiment.

Soda lime was placed in a gauze container and sprayed with 5 per cent lead acetate solution. With a little practice, the quantity of solution required for adequately coating the soda lime was readily determined. The soda lime was then placed in an 8 × 13 cm Waters canister, and this was fitted to the inlet side of a pump with a trap between the canister and the pump. Hydrogen sulphide was introduced in such a way that it mixed thoroughly with the air stream

before entering the canister. The quantity of hydrogen sulphide required to produce a pattern of blackening through the canister was obtained by trial. The air stream was set at 25 l. per min, and after a time determined by experience the hydrogen sulphide was turned off and the canister swept out with pure air. The soda lime was examined without disturbance by gradually drawing off layers by suction.

The results of a typical experiment are shown in figure 2. The dark areas are due to lead sulphide formation. The air stream was flowing in one direction only, so that uniform absorption would be shown by a horizontal edge to the dark area. In fact, as shown, this edge was conical, the dark areas tending to be along the sides of the canister. There was thus clear visual evidence that there is a tendency for the gases to flow so that more absorption takes place in the soda lime in contact with the walls of the canister than in that in the middle. The degree of channelling was unaffected by cotton-wool filter pads, or by small variations in the mesh range of the soda lime.

In view of the close similarity of these results to those of Adriani, this technique was not extended to to-and-fro systems.

These observations have been confirmed and extended by gas analyses. With a filled Waters canister connected to a machine similar to that of Adriani (1941), simulating respiration, gas samples were taken from the various parts of the canister. It was shown that absorption is slightly less efficient at the walls, indicating that the soda lime becomes exhausted there more rapidly.

It has also been found by gas analysis that serious channelling occurs along the top of an incompletely filled Waters canister held in a horizontal position, since a space tends to be formed over the

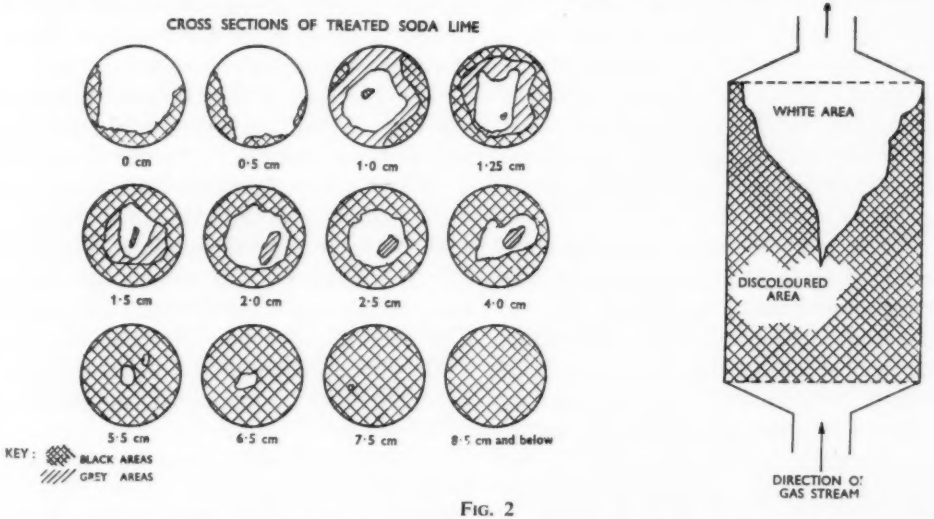

FIG. 2

Results of channelling in circle system. (Using hydrogen sulphide and lead acetate treated soda lime.) Figures refer to distance from top of canister. Canister used in circle arrangement.

top of the soda lime. This reduces the effective life and efficiency of the charge, and can readily be prevented either by ensuring that the canister is completely full, or by using it in a vertical position. Hence this trouble will not arise in a circle type absorber. This channelling has been previously reported (Walls, 1950), and the same author suggests that all channelling may be reduced by using a canister with a corrugated inner surface.

It has also been shown by gas analysis that the presence of a baffle plate in the centre of the canister gauze increases channelling and reduces the efficiency and effective life of the charge of soda lime. In some apparatus this baffle is present in an unsuccessful attempt to reduce dust emission, but would be unnecessary if cotton-wool filter pads were used (see above).

EFFECT OF ATMOSPHERIC EXPOSURE

Some simple experiments have been carried out on the possible deterioration of soda lime when it is exposed to the atmosphere. There are two ways in which deterioration could occur; carbon dioxide could be absorbed from the air, and moisture could be given up or absorbed by the soda lime.

In these tests, moisture contents were determined by finding the percentage loss in weight on heating at 110°C for two hours, and carbon dioxide absorptive capacities by finding the percentage gain in weight when dry 50 per cent carbon dioxide in air was passed slowly for 1½ hours through a tube containing the sample and then anhydrous calcium chloride. This last is the test stipulated in the *British Pharmacopoeia* (1953).

A 6 × 1 inch boiling tube was two-thirds filled with soda lime, and left exposed to the laboratory atmosphere. After approximately 16½ days, a sample withdrawn from the top of the material, on testing, was found to absorb 28.2 per cent of its weight of carbon dioxide. A second sample, from a point slightly lower in the tube, absorbed 31.4 per cent of carbon dioxide. Similar unexposed material absorbed 31–32 per cent of carbon dioxide. Hence it would appear that under these conditions very slight loss of absorptive capacity occurs in the surface layer only.

A more extensive experiment was then carried out. Three open glass dishes 7 cm in diameter and 5 cm deep were filled to a depth of about 3½ cm with soda lime. At the same time some of the same soda lime was sealed in a glass bottle, to act as control. The three open dishes and the bottle were then placed together in a cupboard in the laboratory and left undisturbed until required for testing. After standing respectively for periods of 18, 37 and 105 days, dishes were withdrawn, and tests carried out on material from the top and the bottom. On the first two occasions a sample was withdrawn from the control bottle, and also tested. Moisture contents were determined with the last two dishes. The results are summarized in table I. At the time the second dish was tested (after 37 days), the air in the cupboard was found to have a temperature of 22°C, and a relative humidity of 60 per cent.

A number of deductions may be made from these results.

The moisture content falls fairly rapidly throughout, there being relatively

TABLE I
Tests on soda lime exposed in glass dishes in cupboard.

Source of sample	CO_2 absorption, per cent, after standing for			Moisture content, per cent after standing for	
	18 days	37 days	105 days	37 days	105 days
Top of dish	0.67	0.63	0.19	1.52	0.16
Bottom of dish	27.70	26.70	1.47	2.49	0.26
Control (not exposed)	31.90	31.45	—	15.90	—

little lag between the top and bottom of the dish. This relative absence of lag indicates that the loss is probably due to simple evaporation, where the rate controlling factor is diffusion. Since there are large intergranular air spaces or voids, the depth below the surface of the mass has a very small effect compared with the depth below the granule surface, the mean value of this being dependent on particle size.

The carbon dioxide absorption results are very different. Here the surface layer activity falls very sharply in the first period, while the activity at the bottom initially falls much more slowly. This is due to the fact that carbon dioxide from the air has to diffuse between the granules, in a similar manner to the moisture, to be absorbed. However, it will not at first penetrate so deeply since it will nearly all be absorbed in the upper layers, and appreciable amounts will not penetrate further until this top portion is approaching exhaustion. Hence with time a zone of exhaustion gradually spreads downwards through the mass.

In these tests, the area of exposure was very large. This makes a great deal of difference, as is shown by the tube experiment. Over a similar period, the surface layer in the dish lost about 97 per cent of its activity, while that in the tube lost only about 9 per cent owing to the smaller air access.

It would appear that unless the exposure is gross or for a very long period, little loss of absorptive activity can be expected except possibly in the top layer. If suspect, this is readily skimmed off. The effect of having a badly fitting tin lid would appear to be very small, since the exposure would be far smaller than in our experiments.

The loss of water vapour, which occurs to a greater extent in an atmosphere of lower relative humidity, is not serious. It has been shown (Adriani, 1945) that this loss is of little significance on a Waters to-and-fro system, though it will reduce the efficiency of absorption in a circle system. In view of the frequent practice of pouring a little water on the soda lime, inefficiency from loss of water would not commonly arise in practice.

There are no grounds for the assumption that soda lime deteriorates in a closed tin if kept for a long period, provided that the tin remains airtight.

ACKNOWLEDGMENTS

We are indebted to the Directors of the British Oxygen Co., Ltd., for permission to publish this paper.

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CARBON DIOXIDE CONCENTRATIONS FOUND IN VARIOUS ANAESTHETIC CIRCUITS

BY

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SOME investigations have been carried out over a period of time on the carbon dioxide concentrations returned to the patient in various types of partial and total rebreathing anaesthetic apparatus.

A number of workers have published data of this type, based, however, on gas analysis of discrete samples, obtained either by turning a tap in time to the patient's respirations, or by collecting complete inhalations, as used by Conroy and Seevers (1943) and Woolmer and Lind (1954). We have found that the first method of "snatch-sampling" with a tap gives uncertain and often incorrect results, and have discarded it. This same fault also occurs in Woolmer's method, since the sampling is again dependent on turning a tap in phase with the respirations. In the method of Conroy and Seevers, a breathing machine was used in which the inhaled gas was retained in a reservoir bag which was part of the machine. These workers obtained very high concentrations, due largely to mixing of inhaled and exhaled gases which was not allowed for.

METHOD

It seemed to us that the simplest solution of this problem was to devise a system of continuous analysis of the gases at the face mask. The time lag of such a system would have to be sufficiently short to enable all variations in concentration over the breathing cycle to be observed and measured.

A laboratory-constructed infra-red gas analyser described by Fowler (1949) has been successfully used by Dubois *et al.* (1952) in an investigation of the variation of carbon dioxide concentration at the lips during respiration under various conditions. More recently, Dornhorst *et al.* (1953) have adapted an infra-red gas analyser to follow this respiratory variation, using it as a clinical test for emphysema.

An infra-red gas analyser was available, and, in view of the success of these workers, was modified for our purposes. This was done by cutting out the meter circuit, including the rectifier and smoothing condenser, so that a modulated A.C. signal, of amplitude dependent on the carbon dioxide concentration in the analysis cell, was obtained. This signal was then fed to a cathode-ray oscilloscope, where the amplitude could be measured at any part of the respiratory cycle by applying a variable known voltage to zero the required portion of the trace on the graticule.

In use, there is always a slight drift on

the zero and the sensitivity, so these must be checked occasionally, using respectively dry carbon dioxide free air, and a standard carbon dioxide/air mixture.

When the gases in a breathing circuit are analysed, the sample will normally be saturated with water vapour at a slightly elevated temperature. Apart from any risk of condensation, large quantities of water vapour will interfere with the analysis, since the vapour has an absorption band in the infra-red, close to that of carbon dioxide. Chemical drying of the gas is inadmissible, as the volume of the sample lead must be kept as small as possible, and the flow kept reasonably smooth. Hence the water vapour was largely removed by passing the sample through a small cold trap immersed in a solid carbon dioxide/trichlorethylene freezing mixture. It was found that the optimum temperature for this was between $-10^{\circ}C$ and $-20^{\circ}C$, a lower temperature cooling the analysis cell and giving a high result.

When the apparatus is used in a closed breathing circuit, the sample must obviously be returned to the system. The point where this is done must not be close to the sampling point, or interference may occur, as the two streams will probably be out of phase with respect to the respiratory variation. It has been found satisfactory to return the sample to the breathing machine where one is used (see later) or to an endotracheal catheter in a human patient. In certain systems, it is permissible to return the sample to the rebreathing bag. Since this means that gas is transported from one part of the system to another, interference will occur unless either the flowrate through the analyser is kept very low, or sampling is only done for short periods. In our work, the second course was adopted, since a flowrate of about $1\frac{1}{2}$ litres per minute was needed to avoid mixing of the gases before they reached the analysis cell, though this minimum flow depends to some extent on the conditions. In any event, it is essential that the connection to the sampling point has as small a volume as possible, but without undue constriction, or the pressure in the analysis cell will be reduced, giving a low result. It has been found that a number of respirations may be observed in a single sampling operation without appreciably disturbing the system.

Hence, the apparatus was as shown diagrammatically in figure 1; in this, for the sake of clarity, the circulatory system for the unused absorption tubes and the analyser case is omitted.

If it was desired to carry out analyses in the presence of another gas which absorbed infra-red radiation in the same wave-length range as carbon dioxide, such as nitrous oxide, this interference was suppressed by filling the unused large analysis cells on both sides of the analyser with this gas.

If desired, the oscilloscope may be combined with a camera, but this was not found necessary in the present work.

For most of the work described here, a mechanical breathing machine was used instead of a human patient. The breathing machine used was similar in principle to that of Adriani (1941), and is illustrated in figure 2. In essence, a bell was moved up and down in a heated tank by a pulley-and-string system connected to a motor, so that the rate and tidal volume

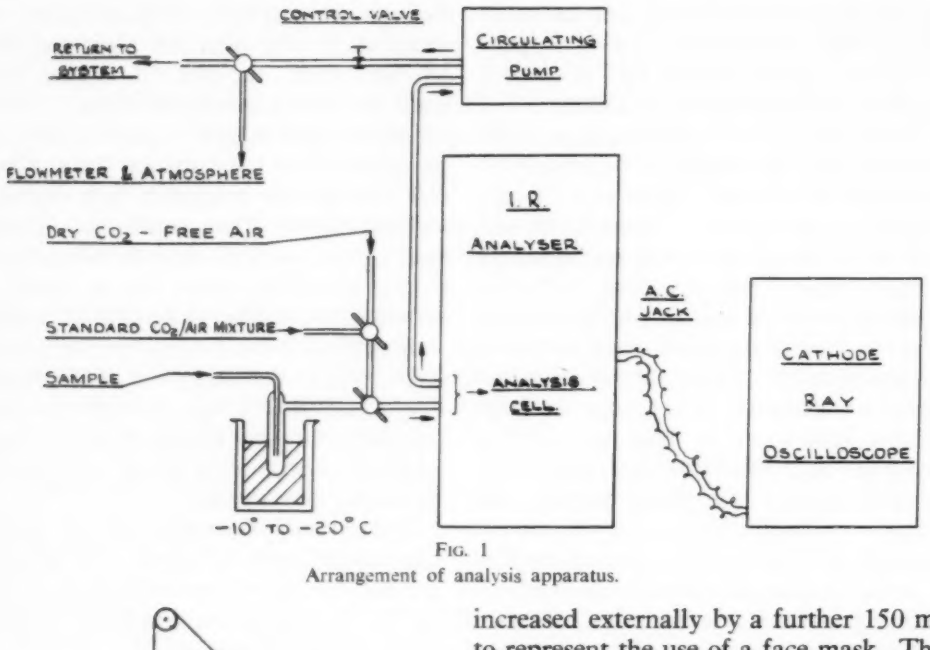

FIG. 1
Arrangement of analysis apparatus.

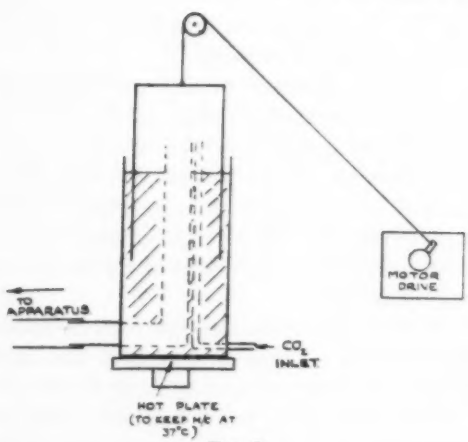

FIG. 2
Breathing machine.

could be adjusted. A tube roughly equal in volume (150 ml) to the average physiological deadspace led to the inside of this bell, and a second tube was used to introduce carbon dioxide at a controlled flow-rate. In our tests, the deadspace was increased externally by a further 150 ml to represent the use of a face mask. The liquid in the tank (a solution containing sodium benzoate and sodium nitrite, to inhibit corrosion) was maintained at 37°C.

This technique has been successfully used in a number of systems. With a human subject, a satisfactory variation in carbon dioxide concentration at the face mask was obtained, which was practically identical with that reported by Fowler (1949), Dubois *et al.* (1952) and Dornhorst *et al.* (1953) for normal respiration. Use of the breathing machine gave rise to some rounding of the trace, due to the much closer approximation of the motion to a sinusoidal form, but the fundamental character was similar, and the resemblance was considered sufficiently close for our purposes.

A further point should be made here

regarding the breathing machine tests. In our machine, the whole of the carbon dioxide inhaled is returned, together with that led in, giving a rising exhalatory concentration. With low concentrations in the inhaled gases, this effect is insignificant, but with higher concentrations will have the effect of increasing somewhat the "alveolar" concentration. When a patient is used, this increase does not occur, but some increase of exhalatory concentration does still occur, due to the recycling of that carbon dioxide present in the deadspace at the end of inhalation. To obviate this would have involved considerable constructional and operational difficulties, and this was not carried out, particularly in view of results with human subjects.

It is considered that the analyses, in the range 0–4 per cent carbon dioxide, are correct to ±0.05 per cent carbon dioxide.

RESULTS

Circle Type Absorbers.

The principle on which this type of unit operates on closed circuit is such that it is normally impossible for gases entering the unit from the patient to be returned to him without passing through the soda lime when this is in the circuit. Hence, provided the canister filling is effective, the only carbon dioxide returned to the patient will be from the deadspace between the patient and the T-piece, together with a little carried into the inhalatory tube during exhalation by turbulence and diffusion.

Two units of this type were examined, the Boyle Mark II Circle Absorber and the Gillies Mark III Apparatus. So far as carbon dioxide absorption is concerned, the units are identical in method of operation. Both were tested as completely closed circuits.

1. *Boyle Mark II Circle Absorber.* Tests on this unit were carried out with the breathing machine running at 20 respirations per minute at a tidal volume of 500 ml, and with a carbon dioxide input of 200 ml per minute (this gave an exhaled concentration of $4\frac{1}{2}$ per cent). Under these conditions, the inhalatory carbon dioxide concentration at the face mask remained between 0.1 and 0.2 per cent for $4\frac{3}{4}$ hours, then rose sharply, due to exhaustion of the soda lime.

In order to assess the effect of carbon dioxide entering the inhalatory tube during exhalation, this test was repeated with the unidirectional valves of the unit removed, and replaced by rubber flap valves inserted close to the T-piece on the face mask. Under these conditions, the inhalatory carbon dioxide concentration remained at 0.0 per cent for 4 hours, reached 0.05 per cent after $4\frac{1}{4}$ hours, and 0.2 per cent after 4 hours 40 minutes, then rose sharply due to exhaustion of the soda lime.

2. *Gillies Mark III Apparatus.* Tests on this unit were carried out with the same breathing conditions as for the Boyle Circle Absorber. Two runs were carried out with practically identical results. The inhalatory carbon dioxide concentration remained below 0.1 per cent for 4 hours, reached 0.2 per cent after $4\frac{1}{2}$ hours, and then rose steadily due to exhaustion of the soda lime.

The Waters Absorber.

In the Waters absorber, provided the soda lime is efficient, the inhaled carbon

dioxide concentration will depend on the amount reinhaled from the deadspace, and hence, in a closed system, on the volume of the deadspace. When the soda lime is partly exhausted, this deadspace will be increased by the intergranular space in the exhausted part of the soda lime, since this first occurs at the proximal end of the canister, as stated by Orton (1952).

Four runs were carried out with the breathing machine running at a respiratory rate of 20 per minute, with a tidal volume of 500 ml and a carbon dioxide input of 200 ml per minute. In these runs, which agreed well, the inhalatory carbon dioxide concentration entering the face mask was effectively zero for $3\frac{1}{2}$ hours, reached 0.15 per cent, after 4 hours and then rose steadily due to exhaustion of the soda lime, reaching 0.6 per cent in $4\frac{3}{4}$ hours and 1.0 per cent in 5 hours.

A run was also carried out on a conscious human subject (D.M.S.). The inhalatory concentration entering the face mask remained effectively zero for $2\frac{3}{4}$ hours, then rose steadily, reaching 0.6 per cent in $3\frac{1}{2}$ hours and 0.9 per cent in $3\frac{3}{4}$ hours.

The effect of varying the breathing and other conditions has also been examined. Results qualitatively similar to those of Adriani (1946) were obtained.

It is not generally appreciated that the efficiency of a Waters absorber will depend on the care used in filling the canister. Since the canister is normally used on its side, if the soda lime is not reasonably tightly packed it will settle slightly during use, leaving a path of lower resistance along the top. This effect is an extreme form of the channelling described by Adriani (1946) and by Bracken and Sanderson (1955). The effect of ineffective packing has been described by Robson and Pask (1954). We have confirmed experimentally that there is a serious loss of efficiency and effective life if the canister is not tightly packed. This often occurs if canisters are filled from separate 1-lb packages of soda lime, which may not be quite sufficient.

We have found that there is little relation between the inhalatory carbon dioxide concentration and the concentration in the rebreathing bag. The latter always rises sharply a considerable time before a sharp rise in the inhalatory concentration indicates exhaustion of the soda lime. The reason for this is that further absorption takes place on return through the soda lime, as described by Adriani (1946).

We have also found that there is very little connection between the temperature of a canister and the efficiency of its charge.

The Semi-closed System.

Several publications have appeared on the subject of rebreathing in semi-closed systems (without absorption). Molyneux and Pask (1951) have attempted to analyse mathematically the gas movements in such a system, and have produced gas flow measurements, but no gas analyses, to support their calculations. However, as stated by Domaingue (1951), this work is based on a number of incorrect assumptions, the chief of which is that complete mixing occurs of the gases in the corrugated hose and the rebreathing bag. Mapleson (1954) has deduced a mathematical theory for a number of

systems of this type, which seems very adequate except that no allowance is made for any degree of mixing. However, if due allowance is made for this factor, the theory gives a very good account of gas behaviour in these systems.

Faulconer and Laterell (1949) have drawn attention to suboxygenation which occurs in partial rebreathing, due to oxygen depletion of too low an input flow, and Crowley *et al.* (1948) indicate that, when using 80 per cent nitrous oxide in oxygen, the total gas input should not be less than 6 litres per minute. Clement (1951), Swartz *et al.* (1953) and Ruben (1953) have carried out further work on this aspect.

Wynn (1941) states that if the total gas input falls below 5 litres per minute, a dangerous accumulation of carbon dioxide may occur. Hewer (1953) confirms this, and states that the relief valve should be situated as close to the face piece as possible, to reduce deadspace.

Swartz *et al.* (1953) have carried out some inhalatory carbon dioxide analyses with various systems on unanaesthetized patients. High readings were obtained, even allowing for larger deadspaces, varying from 6 per cent at a gas input of 3 litres per minute to 0.8 per cent at 8 litres per minute. The method of sampling is not stated.

Woolmer and Lind (1954) have carried out some inhalatory carbon dioxide analyses, the results of which, allowing for some mixing, are consistent with the theory of Mapleson (1954).

We have carried out some tests on the Magill attachment on the Boyle apparatus, using our breathing machine. For convenience, the gas input consisted entirely of oxygen. Since the breathing machine does not absorb oxygen, the input flowrate was corrected by adding on the equivalent carbon dioxide flowrate into the breathing machine, assuming a respiratory quotient of unity, since this was judged to be sufficiently accurate for our purposes.

In the first tests, the input flowrate was varied while the tidal volume was kept constant at 500 ml, the respiratory rate at 20 per minute, and the carbon dioxide input at 200 ml per minute. The results are given in table I. Equilibrium was reached in 15 minutes at 2 litres per minute, and in less than 5 minutes at 10 litres per minute input. It was found that variation of the valve setting within the effective range had little effect, so this was neglected.

TABLE I

Magill Attachment

Variation of inhalatory carbon dioxide concentration with gas input

Input flow, l./min	2	4	6	8	10
Per cent CO_2 inhaled	2.7	1.35	0.7	0.3	0.1

At a flow of 10 litres per minute and a respiratory rate of 20 per minute, the effect of varying the tidal volume was next investigated. On increasing the tidal volume to 1,000 ml and the carbon dioxide input to 400 ml per minute, the inhalatory concentration remained at 0.1 per cent. On reducing the tidal volume to 360 ml and the carbon dioxide input to 145 ml per minute, the inhalatory concentration rose to 0.3 per cent.

A test was next carried out at an input flowrate of 10 litres per minute, with a tidal volume of 500 ml, a rate of 40 respirations per minute and a carbon dioxide input of 400 ml per minute. An inhalatory

concentration of 0.2 per cent was obtained.

Increase of the deadspace between the face piece and the relief valve increased the concentration returned to the patient, as expected.

We have also carried out some tests on the Boyle Mark II Circle Absorber, used as a semi-closed system with the soda lime out of circuit, for comparison purposes. The relief valve on the T-piece was opened. With the tidal volume kept constant at 500 ml, the respiratory rate at 20 per minute, and the carbon dioxide input to the breathing machine at 200 ml per minute, the input flowrate was varied. It was found that slightly higher inhalatory carbon dioxide concentrations occurred with the absorber ether vaporizer turned on, filled with water. The results are shown in table II.

TABLE II

Circle Absorber

Variation of inhalatory carbon dioxide concentration with gas input

Input flow, l./min	2	4	6	8	10
Per cent CO_2 inhaled, ether full on	4.15	1.6	0.75	0.3	0.15
Per cent CO_2 inhaled, ether off	3.9	1.4	0.7	0.25	0.1

Under normal conditions, both types of apparatus have similar effects at higher input flows, while at low input flows the circle absorber returns a higher concentration. This is due not only to its greater capacity for surging with pressure changes by virtue of the greater volume between the relief valve and the rebreathing bag (as illustrated by the increased concentrations returned when the ether vaporizer is on), but also to its greater opportunities for mixing of inhaled and exhaled gases at the T-piece by eddy formation.

So far as the effect of change in tidal volume is concerned, it would at first sight appear that our results are in conflict with those of Woolmer and Lind (1954). However, mathematical analysis based on the Mapleson (1954) theory with mixing factor, shows that both sets are consistent with theory. The apparent difference is due to the fact that Woolmer used a deadspace of 150 ml, whereas ours was 300 ml. It would be anticipated theoretically that there would be an increase in inhalatory concentration at low and at very high tidal volumes.

The effect of increase in respiratory rate is due to the fact that at a higher rate the gas input has less effect. However, the gas velocities are greater, so that the resistance to flow is higher, and the relief valve is open for a greater portion of the cycle, allowing more carbon dioxide to escape. Hence the net result is due to opposed influences of these effects.

It would appear that, under normal conditions, provided the relief valve is close to the face mask, physiologically appreciable concentrations of carbon dioxide in the inhaled gases do not occur unless the total gas input to the system falls below 7 litres per minute.

CONCLUSIONS

(1) Any type of circle absorber is an effective means for the prevention of reinhalation of carbon dioxide.

(2) A Waters absorber is an efficient means of removing carbon dioxide, provided the canister is completely filled and the mechanical deadspace (including the intergranular space of the exhausted part

of the soda lime) is small compared with the tidal volume.

(3) A semi-closed system with the relief valve close to the face piece does not return an appreciable concentration of carbon dioxide under normal conditions provided the total input gas flowrate does not fall below 7 litres per minute.

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ANAESTHESIA FOR RADIOTHERAPY UNDER HIGH-PRESSURE OXYGEN

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FOLLOWING experimental work on animals it has been suggested that the effectiveness of X-ray treatment of tumours may be increased by the simultaneous administration of oxygen under high pressure (Gray *et al.*, 1953). To determine if these results were applicable to man eight patients with carcinoma have been treated while breathing oxygen at 3 atmospheres absolute in a pressure chamber (Churchill-Davidson *et al.*, 1955). As anaesthesia was essential for this type of treatment a suitable technique had to be developed, and this raised many problems of anaesthetic interest.

OXYGEN TENSION AND RADIOSENSITIVITY

The sensitivity of many different types of cells to damage by X-rays may be reduced by as much as two-thirds if they are deprived of their normal oxygen supply, but will not be greatly increased in the presence of excess oxygen. In man the normal environment of most cells contains oxygen at a tension of about 35 mm Hg, and a rise in the tension will not greatly affect the radiosensitivity; similarly, normally oxygenated tumour cells will not be made much more radiosensitive by increasing the oxygen tension.

Many tumours, however, contain large numbers of cells which, because of poor blood supply, exist under almost anoxic conditions. It is believed that these poorly oxygenated cells may survive such doses of irradiation as may safely be given to patients, but that if the oxygen tension to which they are subjected could be raised to somewhere in the normal range they might become much more sensitive and, further, that this increase in sensitivity may be selective.

Gray and his colleagues have shown that there is in fact a well-marked increase in the relative radiosensitivity of the Ehrlich ascites tumour in mice breathing oxygen at 3 atmospheres pressure; they did not feel able, on the basis of their experiments, to predict the response of any particular human tumours, but believed that "the possibility of substantial differential gain . . . is inherent in any situation in which regions of partial anoxia occur in a human tumour". It was in order to test this possibility that the trial was carried out.

GENERAL CONSIDERATIONS

The administration of oxygen under high pressure necessitated the use of some form of pressure chamber. Before carrying out treatment it was necessary to consider the physiological effects of high pressure oxygen on the patient. It was then possible to define the anaesthetic requirements. As, during irradiation, the patient could not be seen and no-one could be in the same room, some means of making observations at a distance had to be devised. Finally, the risks of fire or explosion had to be considered.

THE PRESSURE CHAMBER

We have used a modified naval diving recompression chamber (fig. 1). This consists of a heavy gauge steel cylinder measuring internally 7 feet 6 inches in length and 2 feet 6 inches in diameter, with a door at the head end. There are two circular observation windows in the door and on the top a window 25 cm square of 1 inch thick Perspex is provided through which the X-ray beam is directed. Copper pipes lead directly, without reducing valves, from four 120 cu.ft oxygen cylinders to the oxygen inlet manifold, the supply of oxygen to the chamber being regulated by a valve. The main exhaust valve, $1\frac{1}{2}$ inches in diameter, connects with a hose through which waste oxygen is passed to the outside atmosphere, while there is also a fine adjustment exhaust valve near the pressure gauge at the head end. There are two adjustable safety valves.

A flat wooden floor within the chamber allows an aluminium trolley to be wheeled into the chamber from its mobile cradle. The patient lies on a conductive rubber

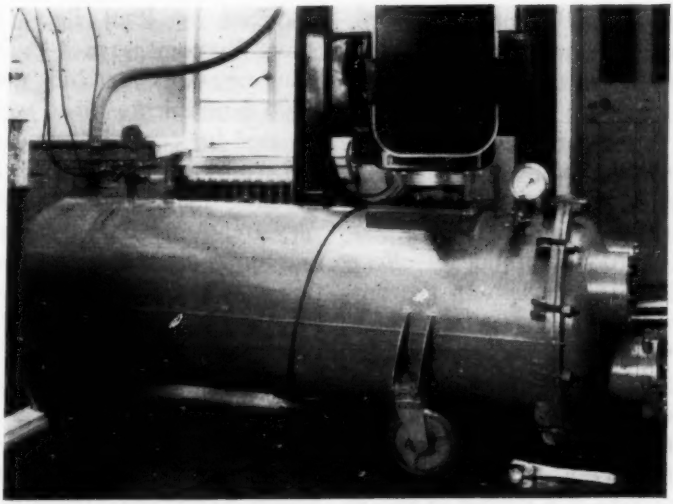

FIG. 1
The pressure chamber in position under the X-ray unit.

mattress and the trolley is electrically connected to the wall of the chamber and thence to earth.

Electrical leads from the patient are connected by a cable passing through the wall of the chamber to a twin-channel cathode ray display unit placed outside the treatment room.

PHYSIOLOGY

Effects of raised barometric pressure.

When the barometric pressure is raised, the tension of the gases dissolved in the blood increases, pressure differentials are caused in those body cavities which do not communicate freely with the atmosphere and there is an increase in the viscosity of the inspired gases (Bean, 1945). If air is breathed, the increased nitrogen in solution in the blood may, on decompression, bubble out and give rise to the "bends" (Caisson disease), but this rarely occurs with oxygen, any bubbles of which are rapidly metabolized. Rupture of the ear-drum or even haemorrhage into the middle ear may be caused unless pressures can be equalized; the conscious subject free of upper respiratory infection is able to do this by opening the Eustachian tubes in swallowing and trained individuals can be compressed from 1 to 7 atmospheres in 90 seconds without ill effect (Case and Haldane, 1941). In the unconscious subject a myringotomy, which heals quickly, is necessary and safe. Pressure differentials in the sinuses may cause pain, but those in the gut do not, at 3 atmospheres, give rise to trouble. Valvular bronchial obstruction may cause rupture of the lung if a pocket of gas at high pressure is left beyond it on rapid decompression, and Case and Haldane have reported pneumothorax in an emphysematous subject from this cause.

The increased viscosity of the gases makes breathing harder and magnifies the effect of any obstruction to respiration. Case and Haldane, for instance, found that breathing through some types of canister was unbearable at 10 atmospheres, and there is a noticeable effect at 3 atmospheres. If compression is rapid the gases to be expired become smaller in volume, and elimination of carbon dioxide is impaired (Bean, 1945). Rapid compression or decompression will also cause marked changes in temperature within the pressure chamber.

Effects of raised oxygen tension.

The continued inhalation of oxygen at high tensions gives rise to oxygen poisoning. In smaller animals severe pulmonary damage (Lorrain Smith, 1899) may cause death, but in man oxygen convulsions, first described by Paul Bert (1878), occur before this point is reached. Donald (1947) found no evidence of lung damage in over 1,000 experiments, all of which were terminated for central nervous system signs and symptoms. The convulsions resemble epileptic fits and the time of onset varies very greatly not only in different individuals but in the same individual at different times. Thus when 36 healthy subjects breathed oxygen at 3.7 atmospheres the time of onset of symptoms varies from 6 to 96 minutes. One of the early, but not invariable, physical signs is twitching of the lips and facial muscles. Although the fits may be repeated if exposure is continued, no serious after effects have been noted. The electroencephalogram shows the characteristic changes of epilepsy,

although these do not come on immediately. Twitching of the lips may occur without any alteration in the electroencephalogram but is detectable by electromyography.

There has been much discussion as to the cause of these convulsions and three main theories have been advanced to explain them. It was originally suggested by Paul Bert (1878) that oxygen exerts a direct toxic action on the brain and Dickens (1946) has shown that at high pressures there is a diminished uptake of oxygen in brain slices *in vitro*, probably due to interference with enzyme systems. Although it has not been possible to demonstrate this diminution *in vivo*, Lambertson *et al.* (1953a) are of the opinion that such a toxic action does in fact exist. A second theory has implicated the rise in tissue carbon dioxide tensions which occurs under these conditions.

Because of the high tension of oxygen dissolved in the plasma the tissue oxygen needs are met without the reduction of oxyhaemoglobin. As this substance is more acid than reduced haemoglobin, base is not made available for the uptake of carbon dioxide. Oxyhaemoglobin also combines less readily than does reduced haemoglobin with carbon dioxide to form carbaminohaemoglobin. Thus, the tissue carbon dioxide tension rises (Samson Wright, 1952). Lambertsen *et al.* (1953b) believe that this rise in the tissue pCO_2 is sufficient to explain the hyperpnoea which follows exposure to high-pressure oxygen, but is not an important contributing cause of the convulsions, and this is supported by the finding of Donald (1947) that symptoms occurred at 2 atmospheres absolute—a level at which carbon dioxide tension is not greatly raised. Finally, cerebral vasoconstriction has been thought to be the cause. Lambertsen found that the cerebral blood flow falls by 25 per cent and cerebral vascular resistance is increased by 55 per cent, but this, he thinks, serves to protect the brain from the direct action of oxygen. This protection may be diminished by the inhalation of carbon dioxide.

Whatever the mechanism may be, it is known that the onset of symptoms is hastened by exercise, heat or cold (Donald, 1947) or by the inhalation of carbon dioxide (Marks, 1944; Kough *et al.*, 1951), and there is evidence that it may be postponed by chloroform (Bert, 1878), barbiturates (Marks, 1944; Taylor, 1954; Churchill-Davidson, 1954) and chlorpromazine (Paton, 1955). While it is possible that the postponement of convulsions may allow time for pulmonary damage to develop, there does not appear to be any evidence in man that this will, in fact, occur; indeed, Donald found that at 2 atmospheres up to 7 hours exposure failed to produce damage.

The other effects of the inhalation of oxygen at high pressure are of little importance. Donald reported bradycardia in some subjects and a rise of blood pressure of the order of 15 mm Hg. Whitehorn and Bean (1952) have reported electrocardiographic changes in decerebrate dogs which may be delayed by vagotomy.

CHOICE OF ANAESTHETIC

To breathe oxygen at a pressure of 3 atmospheres is not in itself unpleasant. The trained subject can rapidly adjust his middle ear pressure, the extra respiratory effort is slight, and indeed there is little

to distinguish the experience from normality. However, general anaesthesia was thought essential in order to minimize the risk of convulsions. It would in any case have been desirable because of the likelihood of ear troubles, sinus pain and claustrophobia in an untrained patient, the necessity of keeping perfectly still during treatment, and the impossibility of an attendant being near the patient.

The inaccessibility of the patient meant that a single-dose technique was required; it also demanded absolute certainty about the airway, which could only be guaranteed by using an endotracheal tube. The first problem, therefore, was to ensure sleep for the requisite time, the second to enable the endotracheal tube to be tolerated, and the third to minimize the risk of complications.

Gaseous anaesthetics were unsuitable because maximum oxygen concentration was wanted, inflammable ones because of the risk of fire, and volatile ones because of the difficulty of control. Intravenous anaesthesia was therefore the choice. Barbiturates, as has been noted, delay convulsions, and sodium pentobarbitone (Nembutal) has a suitable length of action for the treatments used. With improved X-ray apparatus and shorter treatments, sodium thiopentone (Pentothal) or hexobarbitone (Evipan) may suffice. Unfortunately under barbiturate anaesthesia the irritability of the trachea is such that troublesome coughing on the tube occurred in three of the first six cases in spite of careful spraying of the trachea and vocal cords with 4 per cent lignocaine (Xylocaine) and the use of intravenous pethidine. Because it diminishes reflex activity of this type, chlorpromazine (Largactil) was used as well for the last two cases and proved satisfactory. This drug has the advantage of helping to delay convulsions but a theoretical objection to its use is the possibility that changes in the blood flow in the tumour may alter the radiosensitivity; it was thought reasonable to disregard this.

Two further measures to lessen the risk of convulsions were the use of phenobarbitone before treatment and the scrupulous avoidance of carbon dioxide accumulation in the chamber. Because of the increased resistance and the higher temperatures reached by soda lime at 3 atmospheres a modified circle-type absorber (fig. 2) was used which enabled the patient to breathe directly in from the surrounding atmosphere but ensured that all expirations were passed through a Waters canister. Resistance to inspiration was thus minimal and no hot gases were breathed. The slight resistance to expira-

FIG. 2
Modified carbon dioxide absorber. Gases enter at the arrow and are exhaled through the Waters canister. The thermistor is seen in position.

tion offered by the canister could be avoided by relying on a carbon dioxide absorber placed elsewhere in the chamber, but it was thought that this would be less efficient.

Full doses of atropine were given as premedication in view of the finding of Whitehorn and Bean (1952) that vagal section delayed cardiac irregularities, and an opiate was given to allay apprehension. The last two cases were also given pethidine and chlorpromazine.

To keep the bilateral myringotomy incisions open, small polythene tubes were inserted through each drum and removed at the end of treatment. Armstrong (1954), who used this method in the treatment of chronic secretory otitis media, states that even with the tubes in place the hearing loss is only 13.9 per cent.

OBSERVATION OF THE PATIENT

The observations that could be made on the patient during treatment were limited in type by the necessity to avoid using electrical currents within the chamber which could give rise to any risk of sparking. It was thought that an electrocardiograph and a trace of the respiration would give the most useful information. As twitching of the lips is often one of the the early signs of a convulsion, one of the electrocardiograph leads was taken from the upper lip; any muscular activity would then instantly be recognizable by the electromyograph tracing which would become superimposed on the electrocardiograph (fig.4B). For the respiratory trace a thermistor (after Galley and Bareham, 1952) was used. This electronic device, placed at the outlet of the soda lime canister, detects variations in the temperature of the expired gases and thus gives an indication of the frequency and to some extent the volume of the breathing (figs. 3 and 4). Probably further information about the respiration could be obtained from a microphone attached to the endotracheal tube, and it is hoped to incorporate this in future.*

* This has now been done with very satisfactory results.

FIG. 3
Thermistor, mounted for attachment for Waters canister.

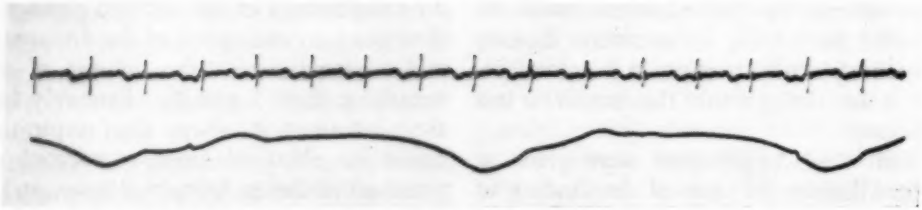

FIG. 4A
Photograph of ECG and respiratory trace. The notches in the latter are caused by closure of the valves.

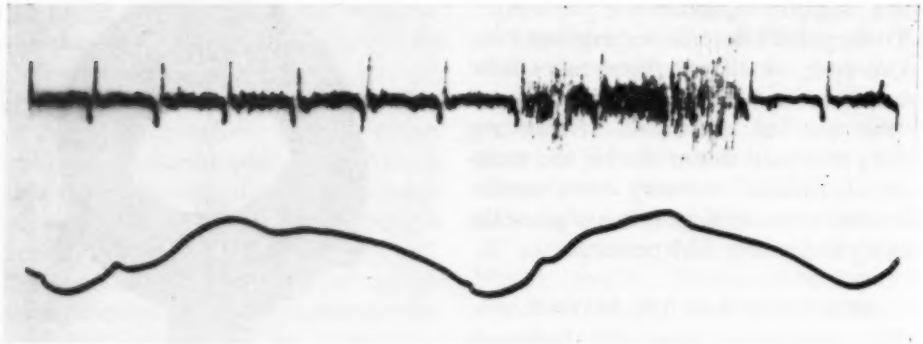

FIG. 4B
Photograph of ECG and respiratory trace. Superimposed on the ECG is an electromyograph produced by voluntary contraction of the lip muscles.

RISK OF FIRE AND EXPLOSION

Materials, including many which are normally non-inflammable, will burn fiercely in oxygen under pressure, and it was therefore prudent to take careful safety measures against fire and consequent explosion. Besides the obvious steps of prohibiting smoking and avoiding the use of sparking electrical apparatus, or any but the most minute current within the chamber, full anti-static precautions included the careful earthing of the chamber and the use of conductive rubber for the mattress and trolley wheels. All waste oxygen was passed directly to the outside of the building to avoid any accumulation within the treatment room.

TECHNIQUE

Preliminary examination.

In the thorough physical examination before treatment particular note is made of the presence or absence of cardiac irregularity, infection of the upper respiratory tract or middle ear, perforation of the drum, or any evidence of bronchial obstruction. A preliminary electrocardiogram is taken. The patient is told the nature of the treatment and warned that there might be some slight transient hearing loss.

Premedication.

Phenobarbitone 1 gr. (60 mg) is given the night before and repeated four hours before treatment. Atropine 1/60 gr. (1 mg) is given one hour before treatment and pethidine 100 mg with chlorpromazine 50 mg injected intramuscularly.

Anaesthesia.

Pentobarbitone sodium (Nembutal) in 5 per cent solution is injected intravenously through a Gordh needle at the rate of 1 ml per minute until consciousness is lost; 0.25 g usually suffices but up to 0.5 g may be needed. Chlorpromazine 50 mg with pethidine 100 mg is then given slowly through the same needle, followed by succinylcholine 50 mg. The patient's lungs are then inflated with oxygen and the largest convenient endotracheal tube lubricated with 4 per cent lignocaine paste passed under direct vision after spraying the trachea and vocal cords with 4 per cent lignocaine from a Macintosh spray. The tube is secured and a metal airway of sufficient size to prevent biting of the tube is inserted. Controlled respiration is carried out until spontaneous breathing returns; this may conveniently be done with 75 per cent nitrous oxide and 25 per cent oxygen during the myringotomy and placing of the polythene tubes through the eardrums, after which the anaesthetic machine is disconnected and the patient allowed to breathe air.

Preparation of patient.

After the X-ray fields have been defined with lead sheeting, the electrocardiograph electrodes placed, and the carbon dioxide absorber connected, the patient is carefully positioned in the chamber (fig. 5).

FIG. 5

Patient, prepared for treatment to region of left lower chest, before positioning in chamber.

The chamber is flushed with oxygen to wash out the air and the door closed. At this stage the oscillograph traces are carefully checked.

Compression.

The exhaust valves are closed and oxygen is allowed to flow into the chamber until the required pressure is reached, about ten minutes being allowed for this. Treatment is then carried out.

Decompression.

Decompression is carried out slowly at the end of treatment, a careful watch being kept on the patient's condition during this stage. If necessary the treatment may be interrupted at any time to enable further doses of pethidine and chlorpromazine to be given, but this involves decompression and recompression and occupies about half an hour. At the end of treatment the polythene tubes are removed from the ears. In an emergency the chamber can be decompressed and opened within two minutes.

RESULTS

The results of the radiotherapy are fully discussed elsewhere (Churchill-Davidson *et al.*, 1955) and it need only be noted here that they were sufficiently encouraging to justify a further and larger trial.

No complications were met with in the eight cases which could be ascribed to the treatment or the anaesthetic. The time of exposure to high-pressure oxygen varied from half an hour to two successive exposures of one hour each. None of the patients had convulsions, nor did any show signs of lung damage. In four patients with carcinoma of the bronchus there was no exacerbation of previously existing symptoms. In one case auricular fibrillation started during treatment; this patient had fibrillated previously and therefore treatment was not interrupted. The fibrillation persisted for some time after treatment but without ill effect. In most cases hearing loss has been unnoticeable to the patient and in the one case in which there was a slight loss for a few days this was due to blood clot on the drum. Drowsiness was prolonged for 24 hours in two cases in which large doses of pentobarbitone were used. Vomiting is likely to occur after X-ray treatment; in this series it was effectively controlled by Dramamine and pyridoxine.

DISCUSSION

To obtain the maximum effect from irradiation it would seem that a certain level of oxygen tension in the tumour must be reached. What this level is, and what is the oxygen tension in the inspired gases which is required to produce it, are questions which, unfortunately, cannot be answered yet. With the technique described, analysis of the gases within the chamber at 3 atmospheres showed the oxygen content to be 91 per cent, and this figure will be exceeded when the chamber is slightly modified. This means that the patient breathes oxygen at a tension of about 2,000 mm Hg as compared with 160 mm Hg in air at normal pressure.

Lambertsen *et al.* (1953c) found that under such conditions the arterial blood contained oxygen at a tension of about 1,700 mm Hg. The extra oxygen is contained in solution in the plasma and must offer a higher head of oxygen pressure to the tissues. Estimates of the tension

reached in the tissues have been made by analysing gas bubbles introduced beneath the skin and by the use of a platinum electrode. Taylor (1949), using the first method, showed that the oxygen tension under the skin of cats was doubled if oxygen at 1 atmosphere was breathed, while Montgomery and Horwitz (1950), using the second method, estimated the tensions reached at 1 atmosphere as 200–400 mm Hg under the skin of human volunteers. Neither of these methods is very reliable, but it is hoped that development of the platinum electrode will enable more accurate estimations to be obtained in some future cases in this work.

In the meantime the optimum conditions in practice will have to be determined empirically. The use of pressures in excess of 1 atmosphere involves a considerable complication in technique and will only be justifiable if the advantage gained is sufficient. The information to be derived, therefore, from a further trial at 3 atmospheres is needed, and will have to be compared with the results obtained at 1 atmosphere.

The anaesthetic technique has been developed to suit the particular requirements of this series of cases and may have to be modified if conditions of treatment are altered. It is, of course, possible to overcome many of the difficulties by training or by using a large chamber and extremely slow compression and decompression as described by Auler *et al.* (1929), who used high-pressure oxygen in the treatment of cancer, but there would still remain the risk of convulsions. The limited experience so far gained seems to confirm the impression that this risk may be considerably lessened, or even eliminated, by anaesthesia, and this alone is a sufficient indication for its use.

SUMMARY

It has been suggested that X-ray treatment given during the breathing of oxygen at high pressure may have an increased effect.

Eight patients with carcinoma have been treated in this way under general anaesthesia.

The physiological and technical aspects of anaesthesia under these conditions are discussed and the method used is described.

No serious complications have been encountered.

The effective rise in tissue oxygen tension is discussed and the necessity for the use of general anaesthesia considered.

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BOOK REVIEW

Geriatric Anesthesia. By Paul N. Lorhan, M.D. Published simultaneously in the U.S.A. by Charles C. Thomas, in Canada by the Ryerson Press, Toronto, and in the British Congress of Nations by Blackwell Scientific Publications, Oxford. Price 23*s*. 6*d*.

It is one of that delightful series known as the Thomas Books. Dr. Lorhan begins with a chapter on the physiological changes that have occurred in the course of years and in the next shows which of these are amenable to therapy and which are not. In the chapter on surgical management he stresses the need of judgment, gentleness and speed, the latter requirement so frequently regarded as of minor importance nowadays. His pre-anaesthetic doses of morphine 1/8 grain (8 mg), atropine 1/300 grain (0.2 mg), strike me as unnecessarily small, particularly as the combination has the advantage of both whilst countering their disadvantages when used alone. There seems to be considerable difference of opinion about N-allylnormorphine. Dr. Lorhan says it "has been found very useful in combating an opiate-induced respiratory depression". Dr. Woolmer seems to agree with him but adds, "because it has some depressant effects of its own N-allylnormorphine should be given cautiously" Dr. Payne, on the other hand, from experiments on 11 volunteers says, "no analeptic effect could be demonstrated while the hypnotic and narcotic actions of the drug were definite deterrents to its use". Of the various anaesthetics in common use, Dr. Lorhan has a good word to say for spinal anaesthesia. He pleads for the use of corrective surgery rather than letting the lesion develop into a possible emergency, and the desirability on the part of the surgeon of employing a competent anaesthetist.

E. Falkner Hill

Brit. J. Anaesth. (1955), **27**, 447

CONTROLLED HYPOTENSION IN AN ADRENALECTOMIZED SUBJECT

BY

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THE operation of adrenalectomy is now gaining ground as a measure in the control of the growth of primary tumour and metastases of breast carcinoma. Patients are usually subjected to this operation when there is recurrence of the growth or metastatic spread after mastectomy and they are subsequently maintained on cortisone therapy.

Wood-Smith and Payne (1955) point out that patients on cortisone therapy are usually sensitive to anaesthetic drugs and tolerate blood loss badly, and Fraser *et al.* (1952) have reported the death of such a patient from immediate postoperative shock in spite of normally adequate therapy. Postmortem examination revealed bilateral adrenal atrophy suggesting adrenal insufficiency. In a review of postoperative adrenaline insufficiency, Root (1955) concludes that it is recognized that a functioning adrenal cortex is necessary for the survival of patients undergoing surgical operation, as intense cortical activity occurs shortly after the beginning of operation and persists for one or two days, but inadequacy of the adrenal cortex may be safely controlled by the use of cortisone.

In view of the delicate physiological balance of adrenalectomized subjects and the fairly recent introduction of the operation, it is unlikely that many persons in this condition have been subjected to further surgical procedures. However, as the operation survival time increases more patients are likely to present for additional surgical operations and the following case is presented as it demonstrates the ability of an adrenalectomized subject to withstand major surgery under anaesthesia, using controlled hypotension.

CASE REPORT

The patient was a well-nourished woman of 30 who had undergone bilateral adrenalectomy and oöphorectomy in two stages, six months previously, and she was now to undergo bilateral mastectomy. The operations were in this order because, when first seen, the growth in her left breast was too extensive for mastectomy with primary wound suture and adrenalectomy was performed in anticipation of a resolution of the growth. This did not, in fact, occur until a course of radiotherapy was instituted four months later.

Following the adrenalectomy she was maintained on cortisone, 25 mg, orally twice daily and on the day of operation for mastectomy she was given 150 mg intramuscularly two hours before operation.

Her pre-operative blood pressure was 110/72 mm Hg, pulse rate 90 and regular. Her haemoglobin level was 82 per cent (Sahli).

Premedication consisted of morphia 1/6 grain (10 mg) and atropine 1/100 grain (0.65 mg), given one hour before operation. Anaesthesia was induced with thiopentone 300 mg and gallamine triethiodide 80 mg and maintained with endotracheal nitrous oxide-oxygen and trichlorethylene.

Hexamethonium bromide 25 mg was injected intravenously and the table put into 10° foot-down tilt, following which the blood pressure fell to 80/60 mm Hg. A further 15 mg of hexamethonium was given and the blood pressure came down to 70/50 mm Hg at which level it stayed throughout the operation, whilst the pulse rate remained constant at 100.

The operation lasted 35 minutes. Haemostasis was adequate, although the cut arteries appeared to have an ample pressure of blood flow and the patient's condition remained satisfactory throughout. At the

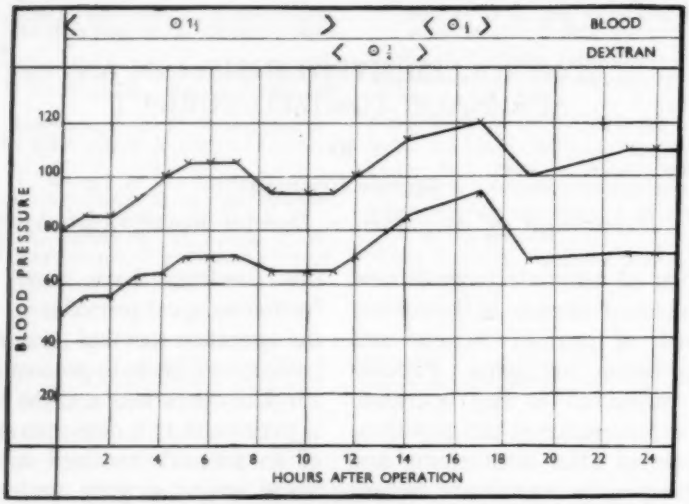

Chart showing blood pressure changes in the period of 24 hours after operation.

end of operation the table was levelled and her blood pressure rose to 80/50 mm Hg.

In view of the possible collapse of this patient in the immediate postoperative period a blood transfusion was started. During the next eleven hours she was given 1½ pints (750 ml) of blood and her blood pressure at first rose to 105/70 mm Hg then fell to 92/62 mm Hg. Her general condition remained satisfactory and her recovery from the anaesthetic was straightforward and complete one hour after operation, but it was considered desirable to keep her systolic pressure above 100 mm Hg. The blood was replaced by dextran 10 per cent and ¼ pint (375 ml) of this solution was given over the next four hours, followed by another ½ pint (250 ml) blood during the next two hours, by which time the blood pressure had risen to 120/95 mm Hg. The intravenous therapy was then stopped and two hours later the blood pressure had fallen to 100/70 mm Hg. Subsequently there was a gradual rise in blood pressure so that 24 hours after operation it reached its pre-operative level of 110/70 mm Hg at which it stayed.

A further intramuscular injection of cortisone 25 mg was given two hours after operation and the patient also required sedation with morphia 1/6 grain (10 mg) one hour and again six hours after operation. These injections did not affect the pattern of the blood pressure changes.

In this case the postoperative blood pressure did not follow the usual pattern of a continued rise following recovery from the effects of controlled hypotension and there did not appear to be any direct cause for the subsequent falls of blood pressure. These falls did not reach dangerous levels and the patient's general condition at no time gave cause for alarm.

ACKNOWLEDGMENT

I wish to thank Mr. F. R. Brown for permission to publish details of his case.

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TRIUMPH OVER PAIN*

BY

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THE institution of a public address such as this, gives the new occupant of a University Chair the opportunity to review his subject, to outline the work of his department and to express both his present enthusiasms and his hopes for the future. I find myself in somewhat a difficult position in these respects, in that it is already seven years since I first came to Cardiff, and I am, in fact, already seeing the first fruits of the project on which I then embarked. I cannot speak therefore in the role of a "new boy". Nevertheless I can still speak with enthusiasm and hope because I have lost nothing of these emotions—indeed I am more than ever enthusiastic and hopeful, since I am increasingly aware of the widening scope of anaesthesia within the field of medicine and of the possibilities for fruitful research and a high standard of clinical work in the congenial and encouraging climate which pervades this Medical School.

This newly created Chair of which I am the first occupant is but the second in the British Empire, the other being that endowed by Lord Nuffield in the University of Oxford. A Chair of Anaesthetics is therefore something of a novelty, particularly so when the emergence of anaesthesia as a specialty worthy of the name, has only taken place within the last two decades. As recently as 1948 when the National Health Service began it was not without some effort and strife that anaesthesia was included among the various branches of medicine, the service of which was to be provided from the most highly trained ranks of the profession.

There was thus little precedent or climate of opinion within the medical or University field to encourage the authorities of this Medical School and of the University of Wales in their venture. Their belief must have indeed been strong that a Chair of Anaesthetics could contribute something to the life of a Medical School, not only in educating the future doctor and specialist and in expanding knowledge within this field of work, but also in enriching the general academic life of a University by the peculiar philosophies and disciplines of this branch of medicine.

In the Spring of last year we heard a most delightful and inspiring address from my colleague the Professor of Obstetrics and Gynaecology on his newly occupying his Chair. In his address he described not only how recent was the appearance of the man-midwife, but with what extraordinary rapidity he metamorphosed into the Professor of Obstetrics. He also showed, and this to me was a most significant part of his address, how this eleva-

* An Inaugural Public Lecture delivered at the Reardon-Smith Theatre, Cardiff, on January 27, 1955.

tion—which but a few years ago was regarded as ludicrous and unnecessary—led to the inevitable attraction to it of first-class brains with the natural and expected result that huge strides were soon made in the field of obstetrics of which the great reduction in the maternal and foetal mortality is a prime example. Anaesthesia has in many respects travelled the same kind of difficult path of advancement as did obstetrics.

The methods of anaesthesia used by the last generation of doctors, were comparatively simple and the impression was general both within the medical profession and outside, that little skill or knowledge was required for the administration of anaesthesia. On the Continent of Europe it was the custom right up to the outbreak of the second world war, in University hospitals for example, for the most junior assistants of the surgical team to take turns at being anaesthetist. In less exalted hospitals the operating room porter, or at best a nurse, would be given the job. In this country, the state of affairs was a little better. Anaesthetics have always been administered by a doctor, though he was, until very recently, almost invariably a general practitioner, to whom anaesthetics were just a side line. Special postgraduate study and training was uncommon until the post war years.

In obstetrics, midwives and general practitioners still play a large part in providing a community service. This is not considered a reason to regard the subject as unworthy of life-long study by the occupants of University Chairs. In the same way medical and lay opinion is now coming to the view all over the world that the long term detailed study of anaesthesia should not be excluded simply because it is possible for almost any doctor or nurse to learn with little effort the manual techniques of administration of simple anaesthesia. This comparatively recent attitude is a direct result not only of the way expert anaesthesia has made possible striking advances in certain branches of surgery, notably that of the lungs, the heart and of the central nervous system, but also because of the patently obvious reduction in mortality and morbidity which comes with expert anaesthesia. The records of almost any hospital, and I know those in Cardiff were no exception, would show that a dramatic fall in the mortality directly due to anaesthesia, follows on the appointment of properly trained and qualified anaesthetists.

Nine years ago, in 1946, world wide celebrations were held of the centenary of of the discovery of anaesthesia, for in 1846 the first anaesthetic as we know it was administered deliberately in a hospital for a surgical operation. It was administered with success, and the surgeon and his assistants were amazed at the silence in the room, the stillness of the patient and the absence of need for strong men to hold the latter down. As for the patient he was amazed to have felt nothing of the operation and to wake up feeling so well after it.

Although we speak of the first anaesthetic as being administered in 1846 the first recorded anaesthetic of course is that in the second chapter of Genesis when Adam experienced a deep sleep in order that a major operation might be carried out on his chest wall. This is not only the first anaesthetic but clearly the most successful one ever, for the results were

FIG. 1

not only entirely satisfactory to the surgeon, but left absolutely no after effects on the patient!

The desire to numb pain has clearly been present in man for centuries. The effects of alcohol in this respect, for example, had already been well known since the day when Noah first stepped out of the Ark on to dry land, and celebrated his survival with the fermented juice of grapes. The pharmacological effects of alcohol having been thus established, this substance became well known after that as a soporific, useful when taken voluntarily to deaden the cares of the world, or when administered deliberately to spare the condemned the pain of their execution. As for the pain of surgical operations, down the centuries a whole host of substances prepared from natural sources were known and used with varying success for this purpose. Such plant extracts as opium, henbane and mandragora alone or in compound and often nauseous mixtures were all used in attempts to lighten the agony of those who were made to suffer the crudities of early surgery. A strong opinion existed that to obliterate pain was to interfere with the Divine course of nature. As an example of the conservatism of by-gone generations, it is on record that at the end of the 16th century a Scottish lady of rank—Euphanie Macalyane—begged her midwife for some relief for her pains of childbirth. This came to the ears of James VI of Scotland afterwards James I of England,

FIG. 2

known as the "wisest fool in Christendom". His zeal as a searcher after witchcraft was such that the poor woman was on this account burnt alive at Castle Hill.

Until the 19th century surgery consisted of little more than treating the injuries of war or accident—trephining the skull for one reason or another, extraction of teeth, incision of abscess and the removal of obvious and easily accessible tumours. Infection was rife and carried off a high proportion of the victims.

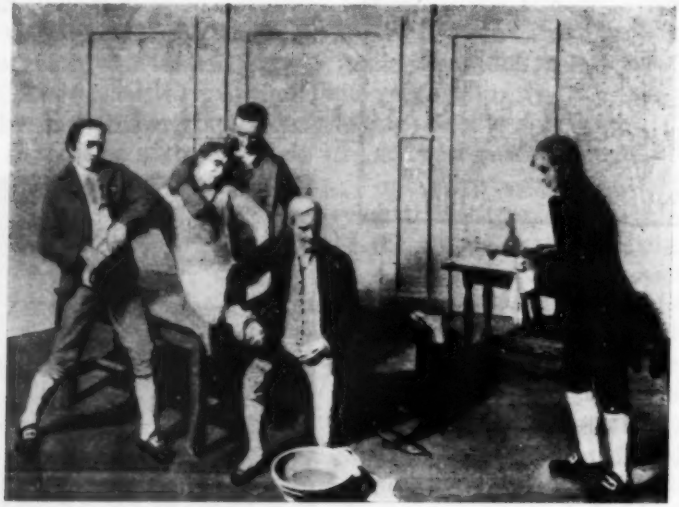

FIG. 3

Arrest of haemorrhage was primitive and this cause accounted for a still further proportion. It is perhaps understandable that the question of allaying pain did not seem important in comparison. Nevertheless, one cannot help wondering what sort of men the then leaders of surgery were who could day after day and month after month carry out their daily work, operating on patients writhing in agony, held down by strong porters, while in their ears rang and echoed the shrieks of pain of their patients.

Not all surgeons were like this. It is said of Sir James Young Simpson, later to acquire fame as Obstetrician and as introducer of chloroform, that as a medical student "after seeing the terrible agony of a poor Highland woman under amputation of the breast, he left the classroom and went to the parliament house to seek work as a writer's clerk". These were the days when the skill of the operator was measured more by the speed of his operating than by the survival rate of his patients.

I have painted the pre-anaesthetic era —the background to my canvas—in terms which many might consider intemperate. I will let you be the judge of that, for I have a few illustrations taken from the literature of the periods I have mentioned.

The story of how clinical anaesthesia

FIG. 4

was discovered never ceases to fascinate me. I shall here only refresh your memory for the facts have received wide publicity in recent years. At the beginning of the 19th century oxygen and nitrous oxide had already been discovered, and ether had for long been in bottles on the pharmacist's shelf. Even the broad effects of inhalation of these latter two were known, though their utilization in medicine had not yet been thought of. A common, I hesitate to say beneficial, use to which ether was put at the beginning of the 19th century was much the same as a cocktail today. The bright young things of 1800 would gather in their drawing rooms for what became known as an ether frolic. They would inhale a little ether, become inebriated, and have a thoroughly good time, in a manner similar to their modern counterparts at a cocktail party, except that space was then more plentiful, and the effects of intoxication less inhibited. The pleasures of the inhalation of ether and of laughing gas were not however altogether denied to their less wealthy brothers and sisters. For their amusement various gentlemen, often bearing the title of "Professor" would appear at fairgrounds with a bladder of laughing gas or a phial of sulphuric ether and invite

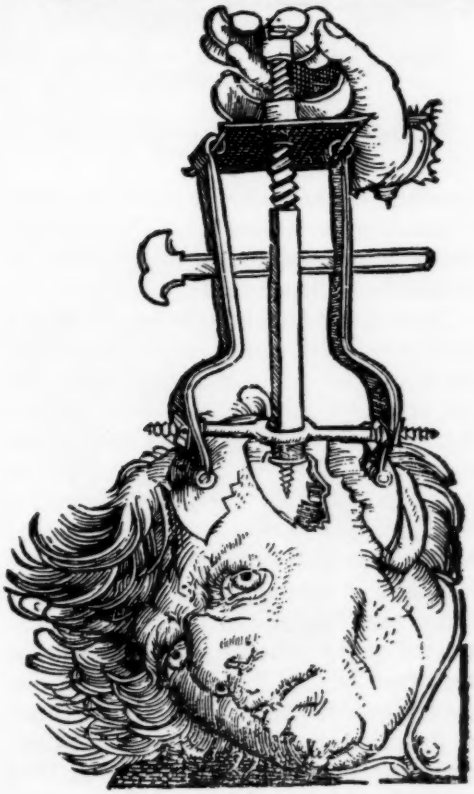

FIG. 5

FIG. 6
An English reaction to the discovery of ether (from *Punch*, 1847)

members of the audience on to the stage to inhale these substances. The drunken antics of the volunteers never failed to amuse the audience vastly.

It remained for a humble but observant dentist in Boston to note that on one of these public exhibitions the person on the stage staggering about under the influence of nitrous oxide struck his leg with some force and yet apparently felt no pain. Subsequent questioning revealed that the man had no knowledge that he had bruised his leg badly, whilst under the influence of nitrous oxide. The next day the dentist had one of his own teeth extracted under nitrous oxide. When he recovered he said "It is the greatest discovery ever made, I didn't feel so much as the prick of a pin". However, a public demonstration of this discovery in 1844 at the local hospital was a failure. This dentist's partner, a certain Dr. Morton, had better success. A local chemist suggested the use of sulphuric ether and the now historic demonstration at the Massachusetts General Hospital on October 16, 1846, was a complete success. There was immediately and for some time to come great opposition to the use of anaesthetics, coming from some of the most reputable surgeons of the day. Thus Dr. Copeland, F.R.C.S., and surgeon to Her Majesty, wrote:

"Even were the reports of persons who felt no pain during an operation, credible, this would not be worth the consideration."

As one recent author puts it, referring to this quotation, "This only shows how a man can occupy a considerable position in the intellectual world and yet be a complete fool in some things."

Another of the many critics was a Dr. James Richmond who, in writing in a newspaper in 1847, said:

"Pain during operations, in the majo-

FIG. 7

rity of cases is even desirable and its prevention or annihilation for the most part hazardous to the patient."

A French physiologist stated that it was a trivial matter to suffer, and a discovery whose object it was to prevent pain was of a slight interest only.

Anaesthesia did not escape the cartoonists' satire, and here are a few of many similar cartoons of the period.

Within a few years the practice of anaesthesia had spread to nearly every country in the world, and anaesthesia, simple and crude as it then was, became routine.

The conquest of sepsis by Lister came soon after, and freed from the twin chains of pain and sepsis, surgery rapidly expanded and flowered into the skilful art and science which it is today.

In 1847, one year after Morton's demonstration, Dr. James Simpson (later to become Sir James Young Simpson) discovered the anaesthetic properties of chloroform and was the first to use this anaesthetic to relieve the pain of childbirth. This, as we now know, it must have done most effectively, but the practice met with a storm of criticism and opposition, not only from doctors, but also, perhaps not surprisingly, from the Clergy.

The controversy did not finally die out until just about the turn of the century. Letters and pamphlets continued to appear condemning the use of anaesthetics in midwifery as being opposed to the Divine will, which had ordained that woman should bring forth in sorrow, and prophesying that its use would be attended by no good either for the patient, her offspring or the world at large. However, most of the criticism was stilled when

FIG. 8

FIG. 9

Queen Victoria elected to have chloroform at the birth of Prince Leopold, in 1853, and again for Princess Beatrice in 1857. It was held thereafter that what was good for Royalty and her Royal progeny, could not but also be good for her people.

There were, however, many more troubles that beset the advancement of this new branch of knowledge. The type of inhalation anaesthetic administered during the 19th century did not require overmuch skill. It was generally held to be work which hardly demanded the services of a doctor at all, and certainly work which did not require any special study or skill. Indeed, in the United States it became largely and still is to a certain extent the province of nurses. That the administration of anaesthetics involved the use of powerful drugs producing loss of consciousness in a few minutes, and which, if given in slight excess, could kill in a few more, seems to have escaped notice then as indeed it often does now. It was inevitable, therefore, that the practice of this work fell into the hands of those regarded by their colleagues as good for little else. These poor exponents of anaesthesia received little or no training whatever and the death rate and the incidence of complications directly due to the anaesthetic was understandably high.

Between the years 1846 and 1914 there were but a handful of men in the whole of the British Empire, if not the world, who devoted sufficient of their time to the study of anaesthesia to deserve the name specialist. It is very largely due to this few that interest in anaesthesia remained alive, and that such minor advancements as there were, took place.

In the first World War the importance of skilled anaesthesia in saving the lives of men dangerously wounded became apparent. The development of the means of administering nitrous oxide for major surgery is but one example of an advance during that war that saved many thousands of lives which would otherwise have been lost. Between the two wars hospitals gradually, but only gradually, began to replace their staffs of general practitioners with men who were prepared, indeed were anxious to make clinical anaesthesia their sole interest. By 1933, when I took up my first junior anaesthetic appointment, many teaching hospitals in London had already instituted such posts for training young anaesthetists.

In 1936 a signal event took place. Lord Nuffield, a man of vast wealth, made donations to the University of Oxford, setting up a number of Chairs and Research Departments in Medicine, which went far to change the place of Britain in the academic world of medical science, and to make it, and Oxford in particular, occupy a position similar to that of pre-war Vienna. Among these original Nuffield Chairs was one in Anaesthetics. The story of how Lord Nuffield came to include, nay to insist, in the face of much opposition, that Anaesthetics *must* be one of these Chairs is another story, but I can at least hint to you that it was partly the result of his own personal experiences of two sorts of anaesthetics, which for want of better adjectives I will label good and bad.

This Department at Oxford, in which I had later the great honour and privilege to serve as First Assistant, was so productive

in original research and so advanced anaesthesia, that it sowed the idea in many an open and receptive mind, that there was still a great deal to be discovered about anaesthetics and that perhaps fields of surgery as yet only dreamed of, would one day become clinical possibilities.

The department of anaesthetics at Oxford, under the virile leadership of Macintosh so recently honoured with a Knighthood by Her Majesty the Queen, became the focal meeting point for post-graduates from all over the world, and in particular the British Empire. Here numbers of men and women were not only trained to carry out the by now complicated techniques of clinical anaesthesia, but to think of this specialty as a branch of medicine in which research could only take place and be fruitful, of knowledge and skill derived from such allied sciences as pharmacology, physiology, physics, chemistry and engineering, were acquired and utilized.

Soon came the inevitable demand from the public as well as from the medical profession for evidence of special training and skill. In 1936, only nineteen years ago, the Conjoint Board of the Royal Colleges of Physicians and Surgeons instituted a diploma in anaesthetics. For many years the possession of the D.A. as it was called served to indicate those who had held approved hospital appointments and undergone special training in this subject. Seven years ago, in 1948, the Royal College of Surgeons of England showed great interest in its sister specialty and established within the framework of the College a Faculty of Anaesthetists. The main functions of this Faculty are Academic, being to regulate, organize and improve the training and instruction of anaesthetists. In 1953, two years ago, the first examination was held for the Fellowship of the Faculty of Anaesthetists. This very difficult and searching examination includes within its scope the basic scientific subjects on which the theory and practice of anaesthesia rest, and the clinical application of anaesthesia to all branches of surgery. The possession of the Fellowship of the Faculty of Anaesthetics has come to indicate a suitability for appointment as Consultant within the Health Service.

How rapid has been the growth of interest in modern anaesthesia, the attraction to it of lively men and women, and the provision of trained specialists for the community is shown by two illustrations of the membership of the Association of Anaesthetists of Great Britain and of the American College of Anesthesiologists.

Having given you a brief outline of the origins, growth and present position of the specialty of anaesthesia, I would now like to touch on some of the features and problems which characterize this branch of medicine in our own locality.

The Department of Anaesthetics in Cardiff was initiated with my own appointment in 1947, a time when preparations for the introduction of the National Health Service were actively being made. The changes which were thereby brought about in the arrangements for providing anaesthesia in the hospitals of Wales were far reaching indeed. I must interject at this point that although my advice was freely asked for and equally freely, and I may say, bluntly, given, the credit for the astonishing improvement in both standard and quantity of anaesthetic service must

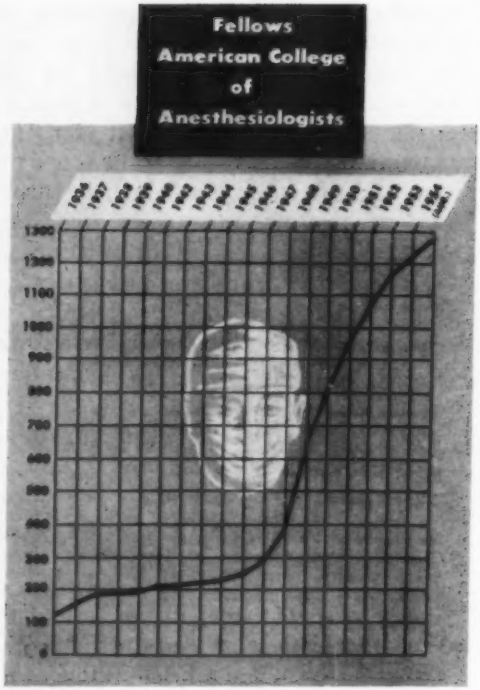

FIG. 10

FIG. 11

go to the two Hospital Authorities concerned and to the School of Medicine, for their readiness to listen to advice, their quick appreciation of the problems involved and their determination to bring about speedily the necessary changes.

On the "Appointed Day" in July 1948, apart from the handful of well trained anaesthetists who had gathered round me in Cardiff, there were only three with a specialist qualification in the whole of Wales. The hospitals throughout the Region then depended almost entirely for their anaesthetic service on general practitioners. These gentlemen gave and had been giving stout and valuable service in this respect. However, their clinical interests were naturally wide and anaesthesia was but one of many. With the numerous calls of a busy practice, most found it impossible to keep abreast of the new, exciting, and complicated advances of anaesthesia, which were opening up new fields of surgery overnight. At the same time the newly appointed younger surgeons fresh from their experiences and contacts during the war years, were demanding for their patients the incomparable benefits of the new anaesthetic methods. Clearly if surgery in Wales was to keep in the tide of surgical progress, anaesthesia too had to keep abreast of the times. With increasing tempo Consultant Anaesthetists were appointed to hospital after hospital. The criteria drawn up by the Anaesthetists' Associations themselves to guide Selection Committees when these consultants were appointed were stringent, and were strictly comparable to those for consultants in other branches of medicine. At the present time, but six years after the start of the Health Service,

every hospital in the whole of Wales at which consultant surgeons work, and many others besides, also has the services of consultant anaesthetists.

From the administrative point of view the result of this change has been an increase in the turnover of major surgical work with better bed utilization, since with modern anaesthesia patients recover quicker from their operations and can go home sooner. Clinically the result has been a great lowering in mortality due to anaesthesia and in the severity as well as number of postoperative complications. As a direct result of good anaesthesia the whole scope of surgery has widened. For example, thoracic centres have been established and in these, operations on the heart and lungs, unthinkable ten years ago, are a matter of daily routine, largely because of anaesthesia. In other fields too, operations unknown a few years ago are now regularly performed, giving hope to those formerly condemned to early fatality. Even the more prosaic benefits of surgery—the operations for hernia, for piles, and similar common ills, are, through the means of improved anaesthesia, made available to patients formerly thought unsuitable for treatment because of their poor general health.

The advent of well trained anaesthetists to Wales has also brought assistance to branches of medicine other than surgery. Because of the anaesthetists familiarity with the handling and administration of gases, with the treatment of disturbances of respiration, with the care of unconscious people in general and because of his preoccupation with the relief of pain of any sort, his advice and practical help is given with a host of problems in other and otherwise unrelated medical fields. The handling of oxygen therapy and respiratory equipment, the treatment of the respiratory troubles of tetanus, poliomyelitis or narcotic poisoning, and the alleviation of intractable pain by various forms of nerve block, are all examples of the way the skill of the anaesthetist is being utilized outside the operating theatre.

I would like here to say one more word about the general practitioner. In some respects it is a pity that in the larger hospitals at any rate he is having to give up his interest in anaesthesia. There are still many occasions of minor surgery or in midwifery when the family doctor is called upon by one of his own fellow practitioners to administer anaesthesia. His skill on these occasions would be greatly enhanced if his connections with the hospital were maintained. It is my hope, and one shared by many others, that some way may yet be found for the general practitioner to maintain an interest in anaesthesia by allocating to him, after he has had adequate training for the purpose, suitable anaesthetic work in the hospitals.

The plans drawn up seven years ago for the provision of an adequate anaesthetic service in Wales are are now almost mature. From practically none, there are now over 30 consultants in the specialty, while in addition to these, there is an even larger number of anaesthetists of lesser training, who occupy more junior posts. In Cardiff itself, an experiment in providing an anaesthetic service is in progress which is somewhat unique in the country. Instead of each hospital appointing its own staff, the clinical area, including both the Teaching Hospital and others, is treated

as one unit and a staff of anaesthetists move freely within the area, meeting all the demands for anaesthetics. This organization, now highly complex, is sufficiently static to meet the needs of daily routine, while remaining sufficiently flexible to allow for contingencies of emergencies and staff sickness and holidays. What is most important is that every anaesthetic in these hospitals is administered by an anaesthetist whose skill matches the problem before him. The arrangement has proved to be a highly efficient and economical one, and may well become a pattern for similar areas in other parts of the country. I have not described the local arrangements to weary you with administrative details. They are relevant to this lecture because the arrangements I have described provide the soil on which has grown up a training centre for anaesthetists and this is a matter well worthy of concern for the occupant of a Chair of Anaesthetics.

Postgraduate teaching is a two-way exchange between students and teacher. The benefit to the former is obvious. The latter receives a constant stimulus to clear thinking and up-to-date evaluation of developments in his specialty. The advantages are by no means only of an academic nature. The hospital service itself gains. The variety of clinical work available in this area and the benefits of association and discussion with a large group of trainees and seniors in an atmosphere of intense clinical interest and enquiry, attract a good number of applicants for junior anaesthetic posts in Cardiff at a time when these posts are becoming increasingly difficult to fill elsewhere.

The instruction in anaesthetics received as an undergraduate is commonly of the sketchiest. If the community is to be well served, therefore, in years to come, and the present high level of anaesthesia and surgery maintained, the training of anaesthetists must be of the highest standard. Postgraduate teaching therefore must be regarded as an important function of a University Department of Anaesthetics.

The teaching of practical anaesthetics, however, presents special problems, since it is next to impossible for the pupil to acquire the necessary skill, confidence and judgment unless he is allowed to take over the administration almost completely into his own hands, with the teacher, at the most, standing near and supervising his actions. Things inevitably often go wrong in the early stages of learning anaesthetics. The surgeons concerned therefore, must be of that kindly temperament and sympathetic understanding without which training in anaesthetics cannot be carried on. To complicate the matter further the degree of skill required in any particular instance must be possessed in some modicum by the pupil, and no possible hazard must be offered to the patient. Learning practical anaesthetics is like learning any manual art. Watching is but a small part of the acquisition of such skill, and can never take the place of practical experience.

The teaching of anaesthetics to undergraduates bristles with even greater problems. No one doubts that the medical curriculum is overburdened with technical detail, almost to the exclusion of the principles that underlie them. Pruning is needed, and indeed has been going on for some years. What are known as the special branches of medicine, some would

have called minor branches, are the first to come under the shears.

The General Medical Council now requires that instruction in anaesthetics shall be received before registration. In fact by 1902 the Conjoint Board already required such instruction before a candidate was allowed to sit for its Conjoint Diploma. The inclusion of this teaching into the medical curriculum is therefore already 50 years old, but anaesthetics in the hands of the infrequent administrator is responsible directly or indirectly for a large number of deaths every year, probably several hundreds in this country alone.

Unlike most other difficult situations which the general practitioner meets in his daily work, when things go wrong during an anaesthetic there is no one but himself available for advice on how to avert an immediate calamity. So long as general practitioners administer anaesthetics, some basic training in this branch of medicine must be given to the undergraduate.

The time set aside for this instruction is pitifully small. In Cardiff, where the attitude to this subject is an enlightened one, only time for four or five lectures in a crowded curriculum can be found for it, and a very small number of hours allotted for practical instruction. Since a teaching hospital of necessity caters for the difficult operation, the rare disease and for the conduct of research in connection with them, it is becoming increasingly difficult to find suitable cases with which to teach undergraduates the elements of anaesthesia, and by elements I mean just sufficient to save one or two lives, during a lifetime as general practitioner. Some leaders in the field of anaesthesia, shocked by the needless waste of life at the hands of inexperienced anaesthetists, hold that anaesthetics should be entirely removed from the undergraduate level and made a subject of postgraduate study alone, so forcing doctors in general to appreciate that anaesthesia should not be practised without special postgraduate training. However, so long as the present regulations of the General Medical Council about anaesthetic instruction are in force, and so long as large areas of the country have to depend on general practitioner services for this work because is would be economically indefensible to do otherwise, then some undergraduate teaching in anaesthesia must continue. I regard the teaching of undergraduates as important for the head of this department and not lightly to be delegated to his junior assistants. My objective has been towards producing a general practitioner who can administer with comparative safety the simple type of anaesthetic which he is likely to be called upon to administer, for his general practitioner colleagues when they are performing their equally simple surgery.

Good teaching, postgraduate in particular, and indeed undergraduate too, only flourishes in an atmosphere of inquiry. Research and teaching go hand in hand, neither truly flourish alone. It is an accepted and indeed vital function of a University department to contribute its quota of endeavour to increase knowledge, and to advance the frontiers of its subject. If this endeavour is to be fruitful, men and materials are needed. The paramount importance of the former has never been

in dispute. Of the importance of adequate material facilities in the shape of physical space and equipment, opinion is not so unanimous. That far reaching scientific discoveries were made in the past in garrets or cellars need not blind us to the essential simplicity of the experimental work of the period. Nor did it prevent the erection of the many vastly complicated scientific research buildings in Universities around the world. Medicine moves more slowly and its eye is less keen. The Medical School and Teaching Hospital in Cardiff have been forward-looking, as they have demonstrated by instituting this Chair. They have already made available to the Department of Anaesthetics some small laboratory acommodation, and this is being put to good use. Nevertheless, some sense of frustration and confinement is inevitable since wide horizons cannot be scanned through narrow windows. Research work in anaesthetics inevitably involves the sister sciences of chemistry, engineering, physics, pharmacology, and physiology. Rarely can a problem be confined to any one of these; it generally spreads into three or four. As important as laboratories are rooms in which staff can meet and hold conferences at frequent intervals. The proper housing of books and places for writing and study are also vital. All these and like facilities are still lacking, excused only by the restricted space, in hospitals never designed for present day needs. There is unfortunately nowadays an almost complete absence of the one-time benevolent donor on whose gifts of buildings many a research department was built up. However, I can report with some satisfaction and with gratitude, that certain commercial and pharmaceutical firms, interested in anaesthetic apparatus and anaesthetic drugs, have made some small contributions to the finances of the department which will ease what would otherwise have been a considerable burden on this still small Medical School. We in Cardiff look forward with buoyant hope to the new Teaching Centre in which the material facilities I have described, and indeed many others too, will be made available.

I have now sketched for you in outline, the place of anaesthesia in medicine and the medical school of today, on a canvas whose background is in the sombre hues of the pre-anaesthetic era of pain and death. I have put in, with perhaps a little of the proud touch, the highlights of the happy developments of this specialty within Cardiff and the Welsh Region, giving you some account, too, of the problems of teaching and research in this subject. I have so far said little of the functions of the occupant of the new Chair of Anaesthetics, whose inaugural lecture this is. His function can be stated in comparatively simple terms. It is to lead and to enthuse juniors, to teach, not only his assistants and pupils, but also himself, to advise authorities and colleagues on both administrative and clinical problems, and to conduct research. To do all these things and to do them passingly well, the most pressing of his requirements is time. Time to read, time to talk, time to plan, and principally time to think. Time for him simply means an absence of need to watch the clock.

I have already realized as a departmental head the truth of what so many of my more senior and more experienced

colleagues in the academic world of medicine complain of so bitterly. I refer to the heavy burden of routine clinical and administrative work. The operative word here is routine. Clinical work, I must emphasize, is the very life blood of a professor in the medical field. To be denied access to or desire freedom from clinical work is to invite an atrophy and a sterility of thought, since medicine without sick human beings is not medicine at all but some other work. It is routine that is the destroyer. It is the belief that repeating a procedure a thousand times teaches more than doing it ten, when there is no attempt to inquire into, evaluate, observe and improve after the first five.

My brief description of the function and needs of a university professor in a medical school, however, does not mean a correspondence with that somewhat mythical figure—the absentminded professor with hat flapping, clothes untidy, feet in tatters and head in the clouds. A professor in a medical school of today must be a man of the world, in close and intimate touch with the life of the human beings who form his clinical work, able to take his part in the complex machinery of a modern hospital and medical school, and to leave his mark in teaching and research upon not only his own students, but upon medicine in general.

Until surgery itself becomes unnecessary, anaesthesia has a vital part to play in the conquest of disease. We have travelled only a part of the road, towards removing the dangers and difficulties of anaesthesia, and towards solving the many problems yet to be posed by surgery. The journey is immeasurably speeded up by such far-sighted and courageous actions as shown by this Medical School in establishing a Chair of Anaesthetics.

The investment they have made, will give good dividends in Triumph over Pain and a handsome profit in terms of human lives.

ON CHLOROFORM AND OTHER ANÆSTHETICS

THEIR ACTION AND ADMINISTRATION

BY

JOHN SNOW, M.D.

Licentiate of the Royal College of Physicians

(*Continued from page* 417)

Experiment 26. Four and a half grains of chloroform were introduced into a jar containing 600 cubic inches, being three-quarters of a grain to each 100 cubic inches (0.6%), and, the vapour having been equally diffused, two frogs were put in. They tried to climb up the side of the jar, as if wishing to make their escape, and one or the other occasionally ceased to breathe for a minute or two, probably from disliking the vapour, but commenced to breathe again. In about five minutes the efforts to escape ceased, and they only moved to adjust their equilibrium when the jar was disturbed. They were now breathing regularly, and continued to do so till about ten minutes after their introduction, when all voluntary power ceased, and the breathing began to be performed only at intervals. They were allowed to remain till half an hour had elapsed, during the last ten minutes of which time no respiratory movement was observed in either of them. On taking them out, and laying them on their backs, the pulsations of the heart were observed on each side of the sternum. These pulsations were the more distinct, from the lungs being apparently empty. I continued the experiment on these frogs, placing one of them back again, in the course of two or three minutes, in the same jar, with three grains of chloroform (0.4%), and the other in a jar of 400 cubic inches capacity, with five grains (1%). They were laid on their backs, and the heart of the former one, in air containing half a grain of chloroform to each 100 cubic inches (0.4%), continued to beat distinctly and regularly, 45 times in the minute, for four hours that it remained in the jar, and it was not observed to breathe during the whole time although it was watched almost constantly. The respiration commenced again within half an hour after its removal. In about an hour, it recovered its power of voluntary motion, and it was not injured by the long narcotism.

The pulsations of the heart of the other frog, in air containing a grain and a quarter of chloroform to each 100 cubic inches of air (1%), became slower and more feeble, and in a quarter of an hour could not be observed. The frog was left in the jar a quarter of an hour longer, and removed when it had been in half an hour. The under part of the thorax was immediately opened sufficiently to expose the heart. It was moderately full of blood, but not contracting at all, and it did not evince the least irritability on being pricked, either at first or after exposure to the air for some time. It is evident that the heart of this last frog became paralysed by the

absorption into the blood of more vapour, in addition to the quantity that was sufficient to arrest the respiration. The temperature of the room during this experiment was 65° Fah.

The effect of chloroform on the heart of the frog is further shewn by the next experiment.

Experiment 27. A frog was placed in the jar containing 600 cubic inches, with six grains of chloroform (0.8%). In twenty minutes the respiration had ceased, but the heart continued to pulsate strongly. At the end of three-quarters of an hour, the pulsations were more feeble, and had diminished from 40 to 30 in the minute. An hour and five minutes from the commencement of the experiment, no movement of the heart could be observed. The frog was taken out of the vapour, and a portion of the sternum and integuments removed, so as partly to expose the heart, when it was found to be still contracting, with a very feeble undulatory motion. This motion increased in force, and, in a quarter of an hour after its removal, the heart was pulsating regularly and strongly, the ventricle apparently emptying itself perfectly. When the frog had been out twenty minutes, it was placed again in the same jar, with the same quantity of chloroform. In about ten minutes, the heart's action began to fail again; and in about twenty minutes, the slightest movement could no longer be perceived in it. The frog was immediately taken out, and the ventricle of the heart was pricked with a needle. In a few seconds, a slight quivering was observed,—whether the result of the prick is not certain,—and the action of the heart became gradually re-established as before. It was arrested a third time by exposure to the vapour; and, although, in its third removal, the anterior extremities of the frog had become rigid, the heart resumed its action partially, and continued to contract feebly for three or four hours after the rigidity of death had invaded the body and limbs of the animal. The temperature of the room was 62° during this experiment.*

In the human being and all other creatures of warm blood, any vapour which is inhaled and absorbed in the lungs passes at once to the left side of the heart, and as the coronary arteries are the first branches given off from the aorta, the heart must, during the process of inhalation, be always a very little in advance of the rest of the body, as regards the amount of vapour to which it is subjected. This, however, is no source of danger, as regards chloroform, if the inhalation takes place in a gradual and uniform manner; for the heart being able as shown by the above experiments on frogs, to bear a greater amount of this narcotic than the brain, its action continues even after respiration has ceased, if the vapour is added only by a little at once to the blood, as it passes through the lungs. But if the air which the patient breathes be too highly charged with vapour, it is easy to understand how the sensibility of the nerves of the heart may be paralysed, notwithstanding their power to bear somewhat more of this agent than the brain and nerves of respiration. I calculated (page 155) the quantity of chloroform which would suffice to arrest respiration in the adult of average size to be thirty-six minims, provided it were equally diffused through the circulation;

* Lond. Med. Gaz., vol. xlii, p. 414.

but supposing a patient breathes, at any time, air containing ten per cent. of vapour of chloroform, a considerable part of this might enter the lungs at a very few inspirations, for thirty-six minims of chloroform occupy only 37.5 cubic inches, and would be contained in 375 cubic inches of air, and might be breathed in less than a minute; but for the whole of the blood to pass through the lungs occupies a considerable time—I believe about four minutes in the adult—and therefore the portion of blood which is passing through the lungs, at the time when vapour of the above strength is inhaled, must become much overcharged with chloroform, making every allowance for the portion of vapour which is expired again, without being absorbed.

I have observed the manner in which the breathing and circulation ceased in a great number of instances, with the stethoscope applied to the chest of the animal, when the quantity of chloroform contained in the air it breathed was known, and have notes of the result. The animals were chiefly cats, which would otherwise have been killed by prussic acid, or in some other way. In every instance in which the quantity of vapour in the air breathed by the animals was from three to six per cent., the respiration ceased whilst the sounds of the heart were still very distinct, as in Experiment 23, related above; in many instances the heart continued to beat from two to three minutes after the breathing had ceased, and, in a great number of instances,there were one or more gasping inspirations just at the moment when the sounds of the heart ceased. In many cases these gasping inspirations caused the action of the heart to return as in Experiment 23, if the animal had been withdrawn from the chloroform; but this was not always the case, and if the chloroform was still breathed during these gasping efforts, all signs of life immediately ceased in every instance.

When, on the other hand, the air breathed by the animals contained eight or ten per cent., or upwards, of vapour of chloroform, the action of the heart was always seriously affected and rendered extremely feeble, if it did not actually cease, at the time the breathing was arrested. In several instances, indeed, the sounds of the heart entirely ceased before the breathing, as in Experiment 25; and although the chloroform was withdrawn, in this and many other experiments, the moment the heart ceased to beat, and fresh air was drawn in by inspiratory efforts, it very rarely had the effect of restoring the heart's action, although this happened so frequently when that organ had gradually ceased to act on account of suspension of the breathing, by the effect of more diluted vapour.

In order to see more precisely the action of the vapour of chloroform on the heart, when not sufficiently diluted, the chest and pericardium were opened on four occasions, in cats and a rabbit, and chloroform was exhibited by artificial respiration. I was assisted by Mr. Peter Marshall in these experiments, and the following is the account of one of them.*

Experiment 28. A young rabbit, rather more than half-grown, was made insensible by breathing air charged with four per cent. of vapour of chloroform in a

* London Journal of Medicine, April, 1852.

large jar. The trachea was then opened, and a tube was introduced and tied. The lungs and heart were then exposed, by making an incision and removing the lower half of the sternum, with adjoining part of the cartilages of the ribs on each side. The front of the pericardium was also cut away, to expose the heart. Whilst these operations were performed, artificial respiration was kept up by means of a bladder of air attached to the tube in the trachea. The heart contracted vigorously and quickly, and the lungs were of a light red colour. The rabbit was beginning to show signs of returning sensibility, when the bladder of air was changed for one containing ten per cent. of vapour of chloroform. The bladder contained 125 cubic inches, and twelve minims of chloroform were put in before it was filled with the bellows. Three or four inflations of the lungs only were made, when I perceived that the heart was beginning to be affected, and I changed the chloroform for a bladder containing only air. These three or four inflations of the lungs with chloroform, had the effect of causing the right cavities of the heart to become distended with blood, and its pulsations to become much slower. In two or three minutes, however, the action of the heart was quite re-established by the artificial respiration, the pulsations being vigorous and frequent, and the ventricles being apparently emptied at each contraction. The bladder charged with ten per cent. of chloroform was again attached, and artificial respiration was made with it. The right ventricle began almost immediately to become distended; and, by the time that eight or ten inflations of the lungs had been made, the contractions of the heart were very slow and feeble. Artificial respiration with air was resumed, but without the effect of restoring the action of the heart. The lungs were observed at the time when the right ventricle was becoming distended, and it was noticed that their colour was unchanged. They afterwards became paler, as the artificial respiration was continued after the ventricle had ceased to empty itself. No contractions of the diaphragm were observed after the first inflation of the lungs with chloroform, and the rabbit did not gasp at any time; whilst the cats were observed to make a few gasping efforts at the time when the heart's action was ceasing.

The circumstances of the lungs not changing in colour at the moment when the right ventricle was becoming distended, which was observed in the cats as well as in the rabbit shows that the distension arose from the failure of the contractile power of the heart, and not from impediment to the pulmonary circulation; for, in the latter case, the lungs would have become congested, and of a deeper colour. In one of the cats, it appeared to me that the left, as well as the right ventricle, was distended with blood; but this distension of the left ventricle did not continue.

(*To be continued*)

BOOK REVIEW

Mysterious Waters to Guard. By Wesley Bourne, M.D., C.M., M.Sc., F.R.C.P.(C.), F.L.C.A., D.A., F.A.C.A., F.F.A.R.C.S. published by Blackwell Scientific Publications, Oxford. Price 42*s*.

At first sight the title suggests naval activities or perhaps the best way of dealing with poachers, but Dr. Bourne explains in his preface that it deals with neither of these exciting subjects, but rather with the distribution of the body fluids and their disturbance by anaesthesia and surgery. It consists of a series of lectures given to various associations of anaesthetists from May 1925 to May 1952. There is also an address to a lay audience on "Hospital Sunday" and a chapter on "Impressions of the Centenary Celebrations of Anaesthesia in Great Britain". In the course of the journey during which he collected these impressions he also acquired a number of photographs of anaesthetists well known in this country. The following points are again and again emphasized:

(1) The toxicity of chloroform and in lesser degree that of ether.

(2) The value of avertin and cyclopropane.

(3) The supreme importance of oxygen.

(4) The excellence of spinal anaesthesia, in which, strangely enough, he uses the Etherington Wilson technique, a technique almost universally condemned by those most experienced in spinal anaesthesia.

(5) The desirability of calming the mind by the removal of fear from the prospective patient. For this purpose he relies on adequate premedication and, at least of equal importance, on confidence and assurance on the part of the anaesthetist, spiritual qualities which pass from him to the patient.

A sentence from the section dealing with premedication runs as follows: "Usually it matters little how these [sedatives] are combined, only one tries to give enough to produce the desired effects, that is completely to obnubilate all perceptions and so lessen the shock which comes from fear; effectively to inhibit secretions and so avoid respiratory obstruction; appreciably to reduce the amount of general anaesthetic when such is used; and wisely to cause the induction of anaesthesia to be much easier." This is typical of much of Dr. Bourne's writing. The ponderous ampullosity of the style is wearisome and is apt to distract the reader's attention from the text. In spite of this the book is an accurate and interesting account of this period in the history of anaesthesia. Of curare and the relaxants he has little to say, presumably because he belongs to the precurare age. He realizes, however, that a new chapter has been added to the story of anaesthesia by their appearance. He looks forward to the time when the relaxant properties of curare can be combined with the necessary analgesic power. But why look forward? They are already here in the spinal anaesthetics, for all operations below the diaphragm and even for those above if your artificial respiration is efficient. It is only the route that is objected to. However, as all anaesthetics must sooner or later find their way to the C.N.S., it is not unreasonable to suppose that anaesthetists will find some means of putting them there directly.

That many of the innovations in the bringing about of which the writer took so prominent a part have given place to others is no fault of his, but striking testimony to the rapid evolution of the subject. The text is punctuated with innumerable quotations, from a great variety of sources; Greek, Latin, Russian, French, and the English poets; the last from these suggests not only that pupil and tutor, but all of us, always are in the Presence of God, a Presence more or less realized by us as we are more or less open to the impact of the Spirit.

The printing and paper are all that we expect from Blackwells of Oxford.

E. Falkner Hill

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